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PROCEEDINGS OF THE JOINT CONFERENCE ON RECYCLING MUNICIPAL SLUDGES AND EFFLUENTS ON LAND, JULY 9-13, 1973, CHAMPAIGN, ILLINOIS

COORDINATING COMMITTEE ON ENVIRONMENTAL QUALITY

1973

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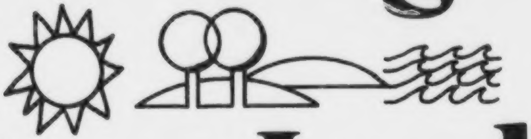

July 9-13, 1973
Champaign, Illinois

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Foreword

Municipal wastewater treatment is one of the Nation's major environmental problems. Treatment and disposal of billions of gallons of municipal wastewater produced each day (approximately 7 1/2 billion gallons in 1972) involves two primary difficulties: (1) environmentally acceptable and economical processing and utilization of sludges generated during treatment, and (2) environmentally acceptable and economical removal of polluting materials from the liquid effluents. Discharge of municipal wastewater has resulted in water pollution and air pollution. The impact of water and air quality standards, the tremendous quantities of sludges produced, and the expenditure of physical and monetary resources for conventional methods of wastewater treatment have prompted a search for alternative methods. One such alternative method, which utilizes our land resources, is known as Soils Treatment Systems (STS). While not a new technology, its prior use has lacked the in-depth evaluations required to assure that STS's are truly environmentally acceptable.

As a consequence of this renewed interest in STS's, the leaders from the Environmental Protection Agency, U. S. Department of Agriculture, and the National Land Grant Universities created a Coordinating Committee on Environmental Quality, recognizing that the utilization of land resources as treatment media required a coordinated attack by multi-disciplinary interests. A subcommittee entitled "Recycling Municipal Effluents and Sludges on Land" was created with the objective of developing and implementing institutional procedures to effectively use the resources available within the EPA-USDA-University structures for a cooperative and coordinated research, development, and demonstration program.

The initial task for this ad-hoc subcommittee was to identify what is known about liquid effluent and sludge application to the land, and what research is needed for successful utilization of land as a soils treatment system from economic, engineering, health, and esthetic points of view. It was felt that the Nation's experts on STS should be contacted to accomplish the above task.

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This document presents information gathered at the Research Needs Workshop, sponsored by the ad-hoc subcommittee on July 9-13, 1973, in Champaign, Illinois. It will provide a firm foundation from which the ad-hoc subcommittee can work to achieve its objective.

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Office of Research and Development

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Federal and State Legislative History and Provisions for Land Treatment of Municipal Wastewater Effluents and Sludges

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INTRODUCTION

Federal and State legislation and regulations that relate directly to recycling municipal wastewater effluents and sludges on land is of fairly recent origin. The Federal government has traditionally left the jurisdiction of this activity in the province of State and local governments, as essentially a public health matter. However, the large amount of Federal grant funds that have been made available, concern about the total environment, and Federal laws and regulations on land, water, and air quality have combined to make the Federal government active in financing and evaluating effective land treatment of municipal effluents and sludges.

State and local governmental units have also shown increasing interest in land treatment of effluents and sludges, both as a desirable method of wastewater treatment under appropriate conditions and as a public health matter which needs guidance and regulation.

It is the aim of this paper to describe the development and present status of the Federal legislation and regulations framework under which land treatment has become of concern to the Federal government and has engendered financial support through Federal grant programs. Also, State and local government laws and regulations are discussed, although there does not appear to be as much information readily available in this area as would be practically useful.

Early Origins of Federal Concern with Water Pollution Control

The precursor of all Federal legislation for water pollution control was the Rivers and Harbors Act of 1899, which in Section 13 of the Act prohibited the discharge or deposit of any refuse into navigable waters. This section, known as the "Refuse Act", required permits for any discharge of any refuse matter of any kind or description into any navigable waters of the United States so that navigation would not be impeded. The meaning of the term "refuse" was defined by a U.S. Supreme Court ruling in 1966. In *United States versus Standard Oil* (384 U.S. 224, 230) refuse was defined so as to include industrial pollutants and to cover all foreign substances and pollutants except for municipal sewerage. Very little enforcement of the provisions of the Refuse Act took place until the early 1970's when concerned individuals and organizations filed so-called *qui tam* actions, which are citizen suits to stop violators of the no-discharge provisions. Also stimulated by citizen concern, over 20,000 permits for industrial discharges were processed by the Corps of Engineers. These permits have now been incorporated into permit activities of the Environmental Protection Agency under the Federal Water Pollution Control Act Amendments of 1972.

Between 1899 and 1948 there was little Federal legislation pertaining directly to water pollution abatement. Exceptions were: (1) the Public Health Service Act of 1912 which provided for surveys and studies of the effect of water pollution on human life, but included no enforcement activities, and (2) the

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Oil Pollution Act of 1924 which prohibited the discharge of oil into coastal waters, but which was not vigorously enforced.

Intermediate Legislation

In 1948, the Water Pollution Control Act was enacted. This was the first legislation that encompassed broad areas of water pollution abatement, including support for research and development and technical assistance to the States. This statute also established the policy that the States were to have the primary role in abating pollution, with the Federal government providing assistance and support. To this day, the States are first given the opportunity to undertake necessary pollution abatement measures on their own, with the Federal government occupying a back-up position. For example, the current permit program under the Federal Water Pollution Control Amendments of 1972 is designed to encourage the States to establish their own permit programs rather than have the program operated by the Federal government.

Overall, the 1948 legislation can be characterized as premised on the basis that pollution abatement was largely of local interest and not of national programmatic concern. This view was held and affected policies until the passage of the FWPCA of 1956.

Modern Legislation

Federal Water Pollution Control Act of 1956

The Federal Water Pollution Control Act of 1956 was the first legislation that authorized Federal grants on a large scale to assist States and municipalities in planning and building facilities for treatment of wastewaters. Under the provisions of this legislation, approximately five billion dollars was appropriated and obligated from 1957 to 1972. Table 1 provides the exact data on the financing. Also included are data on how each State utilized two billion dollars in Federal funds for FY 1972.

The FWPCA of 1956 provided for a series of coordinated actions to prevent and reduce water pollution. The action most pertinent to land treatment was the fact that funds for research and development were greatly increased. This provision later made it possible to begin the financing of the Muskegon land treatment project.

However, the Act and regulations also contained prohibitions and omissions that were not encouraging

TABLE 1
Municipal Wastewater Treatment Works
Construction Grants
Annual Authorizations, Appropriations,
Obligations & Expenditures

Fiscal year	*Authorized appropriation*	*Actual appropriation*	*Fiscal year obligations*	*Expenditures**
1957	$ 50,000,000	$ 50,000,000	$ 50,000,000	$ 844,000
1958	50,000,000	45,657,000†	45,657,000	16,884,000
1959	50,000,000	46,816,000†	46,816,000	36,429,000
1960	50,000,000	46,101,000†	46,101,000	40,295,000
1961	50,000,000	45,645,260†	45,645,260	44,085,000
1962	80,000,000	80,000,000	80,000,000	42,103,000
1963	90,000,000	90,000,000	90,000,000	51,738,000
1964	100,000,000	90,000,000	89,642,425	66,432,000
1965	100,000,000	90,000,000	88,225,123	69,755,000
1966	150,000,000	121,000,000	120,946,373	81,479,000
1967	150,000,000	150,000,000	150,000,000	84,476,000
1968	450,000,000	203,000,000	203,000,000	122,109,000
1969	700,000,000	214,000,000	214,000,000	134,530,000
1970	1,000,000,000	800,000,000	800,000,000	176,377,000
1971	1,250,000,000	1,000,000,000	997,000,000‡	478,366,000
1972	2,000,000,000	2,000,000,000	2,000,000,000‡	413,407,888
Total	6,320,000,000	5,072,219,260	5,067,033,181	1,859,309,888

---

* Payments during fiscal year period.

‡ Includes supplemental requests and appropriations of $657,000 in 1958, $1,816,000 in 1959, $1,101,000 in 1960 and $645,260 in 1961.

† Estimated to nearest million dollars.

TABLE 1: (Continued) Municipal Wastewater Treatment Works Construction Grants Summary of Utilization of Fiscal Year 1972 Appropriated Funds as of December 31, 1972

State	*Allocations*	*Obligations*
Alabama	$ 33,785,150	$ 33,785,150
Alaska	3,548,000	3,548,000
Arizona	17,695,750	17,695,750
Arkansas	19,418,050	19,418,050
California	189,541,250	189,541,250
Colorado	21,738,150	21,738,150
Connecticut	29,350,500	29,350,500
Delaware	5,921,650	5,921,650
District of Columbia	7,800,150	7,800,150
Florida	65,134,450	65,134,450
Georgia	44,438,400	44,438,400
Hawaii	8,074,300	8,074,300
Idaho	7,781,900	7,781,900
Illinois	105,887,000	105,887,000
Indiana	49,976,950	48,169,170
Iowa	27,588,850	27,588,850
Kansas	22,146,850	22,146,850
Kentucky	31,538,750	31,538,750
Louisiana	35,551,850	35,551,850
Maine	10,403,050	10,403,050
Maryland	37,871,250	37,871,250
Massachusetts	54,569,050	54,569,050
Michigan	84,756,550	84,756,550
Minnesota	36,850,650	36,850,650
Mississippi	22,346,700	22,346,700
Missouri	45,134,550	45,134,550
Montana	7,534,600	7,534,600
Nebraska	14,898,500	14,898,438
Nevada	5,326,250	5,326,250
New Hampshire	7,846,750	7,846,750
New Jersey	68,549,450	68,549,450
New Mexico	10,670,500	10,670,500
New York	172,839,550	172,839,550
North Carolina	49,155,750	49,155,750
North Dakota	6,876,100	6,874,568
Ohio	101,621,800	101,621,800
Oklahoma	25,212,500	25,212,500
Oregon	20,638,000	20,638,000
Pennsylvania	112,444,900	112,444,900
Rhode Island	9,770,100	9,770,100
South Carolina	25,694,050	25,694,050
South Dakota	7,308,800	7,308,796
Tennessee	38,227,450	38,227,450
Texas	106,900,250	106,900,250
Utah	11,030,650	11,030,639
Vermont	5,137,200	5,137,200
Virginia	44,914,250	44,914,250
Washington	33,037,650	33,037,650
West Virginia	17,657,050	17,657,050
Wisconsin	42,646,650	42,499,350
Wyoming	4,049,450	4,042,922
Guam	2,172,000	2,172,000
Puerto Rico	27,032,550	27,032,550
Virgin Islands	1,957,500	1,957,500
Total	$2,000,000,000	$1,998,036,783

to the land treatment method. These included:

1. The cost of land for sewage treatment, including use of land for an integral part of wastewater processing, was not eligible for grant assistance.
2. No effective regulations were provided for ocean disposal of sludge, which was becoming of prime concern, especially in the East Coast of the United States.
3. Recycling and reclamation of wastewater was not eligible for grant assistance.

Experience under the provisions of the FWPCA of 1956 indicated that new legislation was needed to allow land treatment of wastewaters to compete on an equal basis with other sewage treatment methods, both as to cost effectiveness and adequacy of treatment. This was to be forthcoming in later legislation.

Legislation Increasing Concern about Sludges

Before discussing current Federal provisions for aiding land treatment, attention needs to be given to three legislative provisions that increased concern about the optional disposal of sludges.

National Environmental Policy Act of 1970. The Act stimulated attention to particular kinds of environmental pollution. One of these was the disposal of sludge, principally along the East Coast, by barging it from municipal sewage systems out into the ocean and dumping the sludge so that it accumulated on the sea bed. The Council on Environmental Quality in its report, *Ocean Dumping - A National Policy* expressed alarm at the consequences of such dumping. In the report, it is stated:

> "Ocean dumping of undigested sewage sludge should be stopped as soon as possible and no new sources allowed."

The result of the Council on Environmental Quality report has been renewed emphasis on exploring and utilizing new methods of disposal of sludge, including land disposal, incineration, and as a useful product.

Sections 402 and 403 of the Federal Water Pollution Control Act Amendments of 1972. The Federal Water Pollution Control Act Amendments of 1972 contain specific provisions for aiding land treatment. These provisions are discussed later in this paper. In adddition, the Act includes provisions that make land treatment of increasing urgency.

For example, Sections 402 and 403 of the 1972 Amendments require that there can be no ocean disposal of sludge without a permit, and permits are to be issued only when it is in the public interest. The permit provisions definitely lead to serious consideration of means other than ocean disposal of sewage sludges, especially land treatment.

Section 301 of the Federal Water Pollution Control Act Amendments of 1972. An additional stimulus to finding innovative means of disposal has been Section 301 of the 1972 Amendments. This section requires that all publicly-owned treatment plants process their wastewaters so that effluent limitations based on secondary treatment are achieved by 1977 (or 1978 for certain projects which are under construction). This secondary treatment requirement will result in large increases in the amount of sewage sludge, since under the definition of secondary treatment, all floatable solids and, in general, 85 percent of suspended solids will have to be removed from municipal wastewater effluents.

These three influences (the CEQ report, permits for ocean disposal of sludge, and the secondary treatment requirements) will add to the amounts of sewage sludge to be disposed of and increase the urgency of finding new ways to handle the vast quantities of sludge.

Federal Water Pollution Control Act Amendments of 1972

The Federal Water Pollution Control Act Amendments of 1972 were enacted on October 18, 1972. This Act has been characterized as the most comprehensive, and at the same time, the most complex, legislation that has ever been enacted to clean up the Nation's waters. A sweeping Federal-State-local government campaign is mandated, aimed toward preventing, reducing, and eliminating water pollution.

Title II of the Act authorizes a multi-billion dollar program to assist communities with 75 percent Federally funded grants for constructing sewage treatment facilities. Such facilities include sewage treatment plants, land treatment, interceptor sewers, sewage collection systems, and separation of combined and sanitary sewers. The particular configurations and processes of any assisted sewerage project must be chosen on the basis of the most cost effective method over the life of the works.

It would be possible here to discuss all the details of the legislation that could affect the applications of land treatment, but it will suffice to discuss the provisions that are most directly concerned with land treatment. There are two sections, Sections 201 and 212, that need special attention.

Section 201 (d), (e), and (f). Subsections 201 (d), (e), and (f) of the legislation were proposed by Congressman Vander Jagt of Michigan on March 29, 1972, in order to insure that recycling and reclamation of wastewaters would be eligible. The final Act contains the exact text as proposed by the Congress.

Sections 201 (d), (e), and (f) read as follows:

> "(d) The Administrator shall encourage waste treatment management which results in the construction of revenue producing facilities providing for—
>
> (1) the recycling of potential sewage pollutants through the production of agriculture, silviculture, or aquaculture products, or any combination thereof;
>
> (2) the confined and contained disposal of pollutants not recycled;
>
> (3) the reclamation of wastewater; and
>
> (4) the ultimate disposal of sludge in a manner that will not result in environmental hazards.
>
> "(e) The Administrator shall encourage waste treatment management which results in integrating facilities for sewage treatment and recycling with facilities to treat, dispose of, or utilize other industrial and municipal wastes, including but not limited to solid waste and waste heat and thermal discharges. Such integrated facilities shall be designed and operated to produce revenues in excess of capital and operation and maintenance costs and such revenues shall be used by the designated regional management agency to aid in financing other environmental improvement programs.
>
> "(f) The Administrator shall encourage waste treatment management which combines 'open space' and recreational considerations with such management.

In introducing this provision (as recorded in the Congressional Record of March 29, 1972, p.H2740-41), Congressman Vander Jagt made a fervent appeal in these words:

> "The concept of clean water for America is a new concept, and we need to encourage our people all we can to look at anything that is new and promising.
>
> James Russell Lowell told us years ago that:
>
> New occasions teach new ideas; we
> Cannot make their creed our
> jailer.
> They must forever onward sweep,
> and upward.
> Who would keep abreast of truth.
> Nor attempt a future's portal with
> A past's outdated key.
>
> Today we stand before the future's portal of a new America. To open that door we should not automatically pass one of nature's own keys. Can we not choose the key of tomorrow? It it does not fit then, nothing is lost, but, if it does fit then for heaven's sake let us open the door and walk into the future of clean water for America."

Congressman Vander Jagt's amendment was voted to be included in the legislation by the margin of 250 to 130. Therefore, recycling and reclamation of wastewaters have been given particular attention in the bill.

Section 201 also contains under its Subsection (g)(2) provisions that require consideration of appropriate alternate waste management techniques. They read as follows:

> "(g)(2) The Administrator shall not make grants from funds authorized for any fiscal year begining after June 30, 1974, to any State, municipality, or intermunicipal or interstate agency for the erection, building, acquisition, alteration, remodeling, improvement, or extension of treatment works unless the grant applicant has satisfactorily demonstrated to the Administrator that—
>
> (A) Alternative waste management techniques have been studied and evaluated and the works proposed for grant assistance will provide for the application of the best practicable waste treatment technology over the life of the works consistent with the purposes of this title; and
>
> (B) as appropriate, the works proposed for grant assistance will take into account and allow to the extent practicable the application of technology at a later date which will provide for the reclaiming or recycling of water or otherwise eliminate the discharge of pollutants."

In commenting on this subsection, House Report No. 92-911 on the 1972 Amendments comments on pages 87-88, as follows:

> "The Committee believes that applicants must in the future be required to examine a much broader range of alternatives for the treatment of pollutants than they have heretofore typically done. It expects the Administrator to provide leadership and to stimulate research to assure the development and application of new treatment techniques. In arriving at the best practicable waste treatment technology consideration must be given to its full environmental impact on water, land, and air and not simply to the impact on water quality. There may be no net gain to the Nation if we adopt a technology to improve water quality without recognizing its possible adverse effect on our land and air resources.
>
> The term 'best practicable waste treatment technology' covers a range of possible technologies. There are essentially three categories of alternatives available in selection of wastewater treatment and disposal techniques. These are (1) treatment and discharge to receiving waters, (2) treatment and reuse, and (3) spray-irrigation or other land disposal methods. No single treatment or disposal technique can be considered to be a panacea for all situations and selection of the best alternative can only be made after careful study.
>
> Particular attention should be given to treatment and disposal techniques which recycle organic matter and nutrients within the ecological cycle.
>
> In defining 'best practicable waste treatment technology' for a given case, consideration must be given to new or improved treatment techniques which have been developed and are now considered to be ready for full-scale application. These include land disposal, use of pure oxygen in the activated sludge process, physical-chemical treatment as a replacement for biological treatment, phosphorus and nitrogen removal, in collection line treatment, and activated carbon absorption for removal of organics. Planners must also give consideration, however, to future use of new techniques that are now being developed and plan facilities to adapt to new techniques."

A caution should be added here, however, that consideration apparently should be given to land disposal techniques only where it is appropriate to do so, since in the Conference Committee the language of 201(b) of the Act was changed to read that waste treatment management plans and practices are required to consider advanced waste treatment techniques, rather than "advance waste treatment technology and aerated treatment spray-irrigation technology." Therefore, land treatment must compete with other possible treatment systems on a cost/ benefit basis. Also, Section 212(2)(c) of the Act requires that any grant application "contain adequate data and analysis demonstrating such proposal to be over the life of the works, the most cost efficient alternative."

Section 212. Section 212 of the Act, which covers definitions, specifically authorizes site acquisitions of the land that will be an integral part of the treatment process or is used for ultimate disposal of residues resulting from such treatment. This provision will allow the land that is used in the actual treatment, such as the land that is used as a filter in the Muskegon project, to be an eligible cost in a grant. However, the land that is not so used, such as the real estate upon which a conventional secondary treatment plant is located, will continue to be a non-allowable cost.

The foregoing comments on the Federal legislation of 1972 are meant to be illustrative of the present status and trends in the legislative history. The comments are subject to revisions as new interpretations and legal rulings on the law are made.

EPA Grants for Sewage Treatment Projects

It will be useful here to list the major requirements for EPA grants for sewage treatment projects:

- All projects must have a priority certification from the State and conform to planning requirements.
- All projects must be analyzed for cost effectiveness.
- Pretreatment of industrial wastes is necessary.
- Environment assessment is necessary.
- Secondary treatment is required, with best practicable control technology applicable for grants financed with FY 1976 funds or later.
- All projects must also meet planning requirements to be processed through the State Agency.

The requirements for grant processing are contained in EPA's so-called Title II Regulations which were published in interim form on February 28, 1973, with Federal Regulations to be published in final form in the Fall of 1973.

An innovation in the regulations is the introduction of a three-step method of making grants. *Step 1* allows a separate grant for the preparation of construction drawings and specifications; *Step 2* provides for a grant for the preparation of construction drawings and specifications; and *Step 3* is for a grant for the building and erection of the treatment works. This division of the financing of a grant for a project will accelerate payments to the communities and allow available funds to be spread over a larger number of projects so that pollution abatement may be accelerated.

Having completed a broad review of Federal legislation, it is appropriate next to consider State legislation.

State Laws and Regulations

State laws and regulations on land treatment are in an early state of development. Surveys of state legislation have been completed by Temple University and the American Public Works Association.

A. The Temple University study, *Green Land: Clean Streams* (Center for Study of Federalism at Temple University, Philadelphia, Pennsylvania 1972), contains a very detailed evaluation of its survey results on State laws pertaining to land treatment. The survey found that 14 States had legislative enactments that were either favorable or unfavorable to land treatment.

The survey also sought to evaluate the attitude of States toward land treatment. Fourteen States were found to be favorably oriented toward implementation of land treatment, three were neutral, and the rest were impossible to judge as to attitude on the basis of available data. Table 2 is a rendition of a chart in the works which tabulates the attitudes of the States.

B. The American Public Works Association Research Foundation study, entitled *Survey of Facilities Using Land Applications of Wastewater* (Chicago, 1973) contains a section on its survey of opinions and regulations of State health and water pollution control agencies on the application of wastewaters on land areas.

The survey led to the conclusion that more attention needs to be given by States to the regulations of land treatment projects. The study expresses it in these terms:

> "If the alternative method of managing wastewater effluents by application on land areas is to become more universally utilized by municipalities and industries it must receive more specific consideration by state health and natural resources authorities than it is now given. The fact that the one thousand and more land application sites now in service in the United States have received minimal regulatory control in the past emphasizes the need for a greater recognition of the problem and a consequent increase in regulatory control in the future."

CONCLUSION

Both Federal and State legislation and regulations related to land treatment are in a state of development. This paper reflects the current situation and the range of actions possible under present rules. The results of research and development, demonstration projects, and working installations will help to determine future legislation and regulations.

DISCUSSION

QUESTION: A. Kaplovsky, Rutgers University. Mr. Sullivan was talking about some of the legislative points that would create some future problems for us that we have to consider. One point that I feel was

TABLE 2
Disposition of the States Toward Implementation of Land Treatment Facilities

Favorable Orientation	*Neutral*	*Negative Orientation*	*Judgement Not Possible on Data Available*
Arizona*	Alabama	Arkansas	Connecticut
California	Alaska	Florida	Delaware
Colorado	Massachusetts	Illinois	Georgia
Idaho		Iowa* *	Indiana
Maryland		Kansas* *	Hawaii
Montana		Maine* *	Kentucky
New Jersey		Michigan* *	Louisiana
New Mexico		Nebraska	Minnesota
New York		Utah	Mississippi
North Dakota		Virginia	Missouri
Oklahoma		Washington	Nevada
Texas			New Hampshire
Vermont			North Crolina
Wisconsin			Ohio
			Oregon
			Pennsylvania
			Rhode Island
			South Carolina
			South Dakota
			Tennessee
			West Virginia
			Wyoming

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* listed alphabetically, not ranked

* * permits land treatment but with restrictions

left out, which I think would be a great concern to most of us, is the fact that the new legislation encourages area-wide regionalization of treatment facilities. If you think a moment how this can affect areas, particularly as it is being looked at in New Jersey, we have to consider that these would include essentially all industry, and that all industrial waste, by a large measure, would be going into regional systems, particularly whether resisting industries from discharging directly to streams, even though their degree of treatment is essentially the same as the public facility that is being planned.

My question, is EPA considering this as "an additional source of sludge" that they have to contend with?

ANSWER: You will find that this cost effectiveness is going to be the answer to your question. If it is more cost effective to go to regionalization, that will probably be the predominant influence. But, I can see many instances, including New Jersey, where it won't be least expensive to go to one large system, and as was mentioned in the Muskegon Project that there could be some tendency with land treatment, whether the necessary factors are present, to break down the system and have several systems instead of one large system.

I don't think that Section 208 of the Act does call for waste management agencies. Section 208 regulations will be issued very shortly. I think you will find that they are very flexible, but if they aren't flexible, please write in so that we can have the benefit of your thoughts and change them before we issue them finally.

QUESTION: William Bauer, Bauer Engineers, Chicago, Illinois. The recent law provides that the land which is used for treatment is eligible for grants, and I was wondering what is the current thinking of the EPA on the matter of funding for land acquisition? On the case of the Muskegon Project the cost of the land was a hundred percent local, but I understand that is going to be changed.

ANSWER: The legislation states that the land that is directly used in the waste treatment is eligible as a cost. The land in a Muskegon type project would be eligible provided the state certifies the project.

Land Application of Wastewater With a Demographic Evaluation

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INTRODUCTION

The American Public Works Association Research Foundation, in 1972, conducted an on-site field survey of approximately 100 facilities in all climatic zones where community or industrial wastewaters are being aiplied to the land, as contrasted to the conventional method of treating such wastes and discharging them into receivinl waters.

Additional data were gathered from many existing land application facilities across the country by means of a mail survey addressed to responsible officials. Another survey was carried out to ascertain the nature and extent of State health and water pollution control regulations governing the use and control of land application systems. To augment information on U.S. practices, a survey was made of experiences gained in certain foreign countries. In addition, an extensive bibliography was compiled of literature on all pertinent phases of land application practices.

The facilities surveyed were relatively large long-established operations. These were selected to obtain as much information as possible on the operating experience of those using this technique. The surveyed facilities whose municipal wastes were applied on land were predominately located in western and southwestern portions of the U.S., while industrial facilities were generally sited in the northeastern section, because this is where the majority of such installations are in service. This method of handling wastewater has been used to meet definable needs and is technically feasible in most areas.

Land application of effluent has been employed for a variety of reasons. Those most frequently mentioned were:

1. To provide supplemental irrigation water.
2. To give economical alternative solutions for treating wastes and discharging them into receiving waters, without causing degradation of rivers, lakes and coastal waters.
3. To overcome the lack of suitable receiving waters and eliminate excessive costs of long outfall lines to reach suitable points of disposal into large surface bodies of water.

Among the major means of accomplishing land application of wastewaters are:

1. Irrigation of land areas by spraying, with high-pressure or low-pressure devices, using either stationary or moveable types of distribution systems.
3. Ridge and furrow irrigation systems.
4. Use of infiltration lagoon or evaporation ponds.

Although facilities of all types were surveyed, this report is primarily concerned with irrigation-type facilities for supplying supplemental water to crop areas, forest areas and unharvested soil cover acreages. The other types are not as widely used, because the climate or soil conditions in some locations have an adverse impact on these alternative methods of applying wastewater to land.

Irrigation-type facilities were found to be used in many instances under a wide variety of climate and soil conditions, with various degrees of prior treatment of the applied wastewater and various types of ground cover utilized.

Each method of application has inherent advantages and disadvantages which must be evaluated for their feasibility and efficacy.

Land application of wastewaters has been practiced extensively in various parts of the world for many years, long before the turn of the century. The majority of earlier facilities applied untreated domestic wastewaters with varying degrees of control and success.

As knowledge of wastewater treatment processes improved, and techniques were developed, confining, in a relatively small area, the entire process needed to produce a "treated" effluent for disposal into receiving waters, land application was relegated, in most states, to being an undesirable and unacceptable process.

New concerns about preserving the quality and reuse of the nation's water resources have resulted in a reawakening of interest in land application as a viable alternative to conventional wastewater treatment and disposal into receiving waters. Increasing volumes of sewage and industrial wastes, growing complexity of such raw wastes, and mounting needs for water to serve growing urban and industrial processing needs, have created doubts about the ability of receiving waters to assimilate effluents which do not meet high-quality standards. In addition, increasing evidence of eutrophication of non-flowing receiving waters has focused attention on the need to eliminate the presence of nutrients in wastewater effluents. Further, the presence of toxic trace elements in effluents is sometimes considered a threat to the safety of receiving waters. Thus, advanced treatment methods have been developed and utilized to avoid discharge of such objectionable components. Inasmuch as land application appears to offer comparable or superior degrees of treatment by augmenting waste treatment with the "natural" purification offered by soil contact, land application is again being considered as one of the acceptable means of achieving full treatment of wastewaters.

However, a most important factor of the current land application concept is that it be limited to the use of *treated* wastes. Generally, effluents are being conventionally treated to meet secondary treatment quality criteria. In at least three observed facilities, applied effluents have received tertiary treatment, to the point where the effluent would fully meet the generally prescribed, as well as proposed, criteria for discharge to receiving waters. Thus, land application is being used to give a degree of advanced waste treatment, including high degrees of nutrient and bacterial removal. In this context, land application can be viewed as an alternative to physical-chemical processes and other methods of ultra-treatment which are designed to achieve a high quality effluent.

Economics of construction cost, operating costs, energy requirements, and efficiencies of performance of land application systems must be balanced with the ability to acquire the right to apply wastewater upon the required land areas. The cost of advanced waste treatment by conventional means must be weighed in the light of the cost and complexities of land application systems.

Two informative reports were published on the subject of land application in 1972. *Green Lands - Clean Streams*, a report by Temple University Center for the Study of Federalism, is a frankly written advocacy of the land application of wastewaters and sludges. *Wastewater Management by Disposal on the Land* by the U.S. Army Corps of Engineers is a thorough review of the physical, chemical, and biological interactions involved in the technique of land application. The Consulting Engineering firm of Metcalf and Eddy has also prepared a companion report for the U.S. Environmental Protection Agency, concerned with engineering considerations of land application systems, entitled *Wastewater Treatment and Reuse by Land Application*. The M& E report will be printed by the U.S. Government Printing Office in 1973. These three reports, together with this report on the study conducted by the AWPA Research Foundation, should be considered in evaluating land application systems, because they deal with somewhat different aspects of the common problem.

The report on the AWPA studies has made no special effort to examine the specific aspects covered in detail in the other reports. Rather, it is concerned with reporting upon the policies, practices and performances of a representative group of the relatively larger land application systems within the U.S.; policies, or lack of policies, of State regulatory agencies; and the experience with land application in certain foreign installations.

Systems which were under construction, such as Muskegon County, Michigan, and several major domestic and industrial systems which were intimately known to Metcalf and Eddy project personnel were not investigated for this report. However, the firm of Metcalf and Eddy has supplied copies of its field interviews at such sites to APWA evaluators and data on many of these installations have been incorporated in this report. Conversely, all field information obtained during the APWA investigations was supplied directly to the firm of Metcalf and Eddy for its use in analyzing its own study results.

Highlights

The following highlights from the field survey are presented to give a composite picture of the observations made during the land application site visits:

1. Communities generally use their land application system on a continuous basis. Food processing plants, the predominant industrial users of the system, generally use discharge-to-land systems for three to eight months per year.
2. Ground cover utilized for municipal systems is divided between grass and crops. Industries generally use grass cover.
3. Land application systems are generally used on a daily basis, seven days per week.
4. Application rates for crop irrigation are very low in terms of inches of water per week. Two inches or less was commonly used. (Two inches per week equals 48,000 gallons per acre per week.)
5. Many types of soils were used, although sand, loam and silt were the most common classification given. Two systems using applications over many feet of sand were applying up to eight inches per day once a week, and one system on clay was applying a daily rate of 0.1 inch.
6. Most operating agencies, municipal and industrial, are planning to either expand or continue their land application installations. The few examples of systems which had been abandoned were due to either the desire to make a higher use of the land, or because of reported overloading and incompetent operation of the land application facilities.
7. Industries surveyed generally treat their total waste flow by land application. Practices of municipalities varied from less than 25 percent, to all the wastewaters discharged.
8. Secondary treatment is generally, but not always, provided by municipalities prior to land application, often times accompanied by lagooning. Industries using this technique frequently treated their process wastes by screening only.
9. Spray irrigation is the most frequently used (57 facilities) method of application, although most municipalities use more than one method. Ridge-and-furrow irrigation is used at 23 facilities and flooding irrigation by 34 systems. Industry generally used spray irrigation.
10. Land use zoning for land application sites is predominantly classified as farming, with some residential zoning in contiguous areas.
11. Wastewater generally is transported to the application site by pressure lines, although a number of municipalities are able to utilize ditches or gravity flow pipelines.
12. Many municipal land application facilities have been in use for several years—more than half for over 15 years. Industrial systems generally have been in use for a lesser period of time.
13. Renovated wastewater is seldom collected by underdrains; rather, evaporation, plant transpiration, and groundwater recharge take up the flow.
14. Land application facilities generally do not make appreciable efforts to preclude public access. Residences are frequently located adjacent to land application sites. No special effort is made to seclude land application areas from recreational facilities and from those who use these leisure sites.
15. Monitoring of groundwater quality, soil uptake of contaminants, crop uptake of wastewater components, and surface water impacts is not carried out with any consistency.

Overview

In order to present all of the details and data relating to the conduct of the studies, and to explore the influence of possible factors influencing the handling of sewage from many sources, at many sites, and with many and diverse methods of application, the APWA report has resulted in a rather large document.

Among other things, the report has been compiled to answer the inquiries of the U.S. Environmental Protection Agency from other U.S. Government agencies, municipalities, industries and engineering consultants. The total report is valuable, not because of its size but due to its contents. This is the first time some of this data has ever been assembled, evaluated and reported. It will become available from the U.S. Government Printing Office in the autumn of 1973 and from the National Technical Information Service (NTIS) of the U.S. Department of Commerce.

This overview is for those who require a brief summary of the contents of the American Public Works Association report, entitled, *Survey of Facilities Using Land Application of Wastewaters*, and an equally concise evaluation of the principles, practices and performances of the land application systems now in service in the United States and in certain foreign countries. Summaries of the basic intent and information contained in each Section of the report are presented as well as a demographic evaluation and a discussion of the fate of materials applied to the land.

The sixteen conclusions drawn from the study serve to verify the relative success of present land application systems for supplementing groundwater sources; providing economical means of effluent utilization where discharge to surface waters would be excessively difficult and costly; affording augmented effluent quality improvement by soil uptake of constituents which would adversely affect receiving water quality; offering opportunities to enhance crop growths and silviculture; and augmenting indigenous water supplies for recreational and aesthetic purposes.

Successful application of effluent wastewaters to land areas is not without its problems. This management technique is not a universal panacea.

The need for public acceptance of land application methods is strongly advocated, particularly for proposed installations covering large volumes of flow to extensive acreage in relatively densely populated regions. Over and above the problem of neutralizing the aesthetic and psychological objections to any direct or indirect contacts with wastewaters or waste residues, unfounded fears of virological or pathological infections must be overcome by carefully planned and effectively executed public education programs.

This public relations problem emphasizes the recommendation that irrefutable findings on the presence or absence of health hazards in land application practices must be defined and reported before guidelines for this method of wastewater effluent management are promulgated. Guidelines are soon interpreted as "the law" rather than *suggested criteria.* This gives credence to the sound suggestion that formalization of "guidelines" be deferred until "interim evaluation procedures" are published and given the opportunity to bridge the gap between today's rather limited use of land application systems and any greatly expanded utilization of this treatment-disposal procedure in the future.

The Study - Section II

The studies conducted by the American Public Works Research Foundation on behalf of the U.S. Environmental Protection Agency were planned and consummated to produce the fundamental information needed to give validity to the intent of Section 201 of the 1972 Amendments to the Water Pollution Control Act such as:

- Affirmation of design and operational data for a large number of U.S. installations in various climatic regions, handling wastewaters of various types and volumes; by various methods of application; for different purposes; on various types of soil, ground cover and cropping; and demonstrating different local environmental conditions and monitoring practices.
- Collection and interpretation of similar data on foreign installations where land application has been in effect for longer periods and under varying conditions.
- Collation of bibliographic records and references on every conceivable facet of land application, including design, operation, physical, chemical, pathological, virological, parasitic, aesthetic, hydrologic, agricultural, herbicultural, silvicultural benefits and detriments, and other related matters.
- Evaluation of all data in terms of practical interpretation of their meaningful answers and guidelines to land application practices.

The studies, in great measure, achieved these goals.

Survey Investigations - Section III

On-site, in-depth investigations of more than 67 community and 20 industrial land application systems were carried out by trained engineering specialists. The 87 installations designated provided data of significance. These sites were chosen to be representative of national experiences with varying types of wastewaters, applied to varying types of soils, ground cover and other indigenous conditions under diverse climatic conditions.

To augment the findings of the on-site surveys, a mail investigation of similar land application sites was carried out, covering the same study subjects explored by the field study team. Significant data were obtained for approximately the same number of municipal and industrial installations covered by the field studies. Five climatic zones, each with their own temperature, precipitation, humidity and seasonal characteristics, were designated. Evaluation of survey findings was interpreted on the basis of the impact of climatic conditions on wastewater application to land areas and other factors influenced by meteorological phenomenon.

The demographic, geographic, geologic, hydrologic and other factors and impacts of land application practices, procedures and performance are discussed in this section.

The findings of the survey offer evidence of acceptable operating experiences, which should be useful in guiding future land application decisions. An important finding, among all of the diverse conclusions that can be drawn from field and mail survey data, is the fact that 90 percent of communities and 95 percent of industries making use of land application methods plan to continue their use; nearly 50 percent of communities and one-fifth of the industries contemplate increasing or expanding their systems. If the "proof of the pudding" is in the performance, the approval of users is the final appraisal of the land application technique.

The study indicated that existing land application systems are serving, predominantly, in relatively small communities and industrial sites, in terms of population and flow loadings. Future applications may involve larger loadings, greater irrigation areas and greater land values, but the expansion of facilities may represent an orderly enlargement of scope and a manageable increase in costs. It is significant that the costs involved in existing land application systems apparently lie within the capabilities of smaller communities and industry installations. Choice of this means of wastewater disposal has been based on various factors: need for supplemental irrigation water; augmentation of groundwater resources; simplicity and economy of providing required degrees of treatment; problems of excessive cost of providing treatment and outfall lines to distant points of effluent discharge into suitable receiving waters; and merely "to get rid of the sewage" in a convenient, trouble-free manner that is acceptable to the community.

The findings of the survey are so manifold and technological that any attempt to capsulate them would hinder their value and endanger their interpretation. The following points are borne out by the report: existing practice stresses land application of treated effluents, not raw wastewaters; the percentage of land application acreage frequently represents only a portion of the land reserved by the owners for their systems; application periods may vary from one month to twelve months a year, and from one to seven days a week, depending on climatic conditions, need for land application for surplusage flows, seasonal industrial processing, such as in the food industry, and other local factors; land values are relatively low, zoned for either agriculture or residential uses, often in undeveloped areas, and subject to minimal degradation of value due to use for irrigation purposes; all types of soil are utilized, with sand, clay and silt most favored; groundwater interference problems influence choice of sites and, after choice of unaffected sites, cause minimal difficulties with land application methods; predominant wastewater distribution methods are spray irrigation, overland flooding irrigation and ridge-and-furrow irrigation.

Use of the irrigated land varies with the owner's needs and dictates, from no ground cover to grass cover, cultivated crops and forested areas. Grass is the most common ground cover in community systems. It is evident that the cropping value of supplemental irrigation with wastewaters and their nutrient components is not universally utilized.

Rates of application of sewage effluents to the land, and duration of uninterrupted application vary from 0.1 inch per day to over 1 inch per day, with varying periods of irrigation and resting. The most commonly used application rate is two inches per week. Few systems are over-stressed by such loadings; it is apparent that increased rates of application could be practiced without jeopardy to the system or the environment, and with more effective and economical utilization of assigned acreages. The follow-the-leader trend in application rates is apparent; proposed guidelines—either tentative or final—would do much to establish more rational application rates, based on facts rather than blind adherence to the accidental or arbitrary rates used by other researchers.

Little concern and protective measures have been shown for the deterioration of the environment in application areas, or to the impact on contiguous lands and their occupants. Security provisions are not universally used to protect against intrusion of trespassers or against the dispersal of on-site conditions to surrounding land areas. Fencing and patrolling is not universally practiced; buffer zones to isolate land application areas and impede dispersal of aerosol sprays are used but no common practice is in effect; monitoring of groundwater, surface water sources, soils, crops, animals and insects is practiced in some locations and minimally used in others, often dependent solely on the requirements of public health authorities.

It is hazardous to characterize the above thumbnail findings as truly representative of the practices and experiences disclosed by the survey. Similarly, these factors do not represent all of the disclosures of the study. They do however, give indication for those who will not study the full text and details of the comprehensive investigations explored in the full report, that land application methods have been found to be workable and relatively amenable to the local environment, even under control and regulatory procedures which must be improved in all future land application practices. The future will require more complete supervision of land application sites, supported by definitive proof of the capabilities of such systems to serve as wastes handling facilities worthy of the term "alternative" techniques.

Opinions and Regulations of State Health and Water Pollution Control Agencies - Section IV

The survey conducted by APWA with State health and water pollution control agencies indicated that most State agencies have no set policies on this phase of wastewater handling or attendant environmental impacts, do not impose specific conditions on installations, seldom inspect existing systems, and seldom require monitoring procedures and the filing of official reports on operation.

Only four States reported rules governing the types of crops that can be grown on sewage-irrigated lands. The few agencies which invoke restrictions of this nature specify the quality of effluents applied to land areas. Of 27 State control agencies which participated in the data-gathering program, a maximum of 25 percent involved themselves with any single item of the 11 guideline criteria covered by the opinion survey.

In defense of this record of irrelevance with the land application practice, it must be said that some States have few such installations and even fewer have installations of any major significance. In addition, States contend that they have been deeply involved with the control and regulation of conventional sewage treatment facilities and stream quality protection. Shortage of qualified personnel has been offered as the reason for absence of attention to the installation, operation and monitoring of land application installations.

In the absence of formal State regulations, some agencies have used unofficial staff opinions as the basis for land application decisions. Similarly, each-case-for-itself decisions on health hazards have been invoked or expressed by State health agencies but a minimum of translation of such policies into specific regulatory actions was disclosed by the survey.

Summary of Foreign Experence - Section V

Data from such widely located countries as Argentina, Australia, Belgium, India, Israel, Hungary, and Mexico confirm the use and value of the land application technique for various purposes, for a variety of growing crops, under diversified conditions, and with different results. Enhancement of soil productivity, through the mechanics of supplemental irrigation with waste water and the enrichment of soil with the organic constituents of sewage and industrial processing waters are widely acknowledged.

Health hazards have been studied in various countries and protective measures have been invoked. Some countries, such as water-short Israel, utilize wastewaters for irrigation purposes—where over 100 systems are in service, but they tend to avoid the use of raw, untreated sewage and contact with crops that are eaten raw by humans or domesticated animals.

On the North American continent, the most dramatic land application system on record is in Tula Hidalgo, Mexico, where lands operated by the Mexican Federal Department of Agriculture are assigned to Ejidos, heads of families, in units of limited hectares. On 47,000 hectares, equivalent to 115,000 acres, some 1,476,000 metric tons of food products were grown in 1971. Approximately the same tonnage was produced in 1972. Additional arid land is available for cultivation when additional wastewater from Mexico City becomes available. Currently some 570 million gallons per day of raw untreated sewage flows by canal to this area, 95 percent of which reach the cropland. During the rainy season there is an additional storm water flow through the same canal, most of which is impounded in a series of dams for use during the dry season for cropland irrigation.

In England the Herefordshire facility has had over 20 years experience irrigating liquid digested sludge containing about three percent solids. Technically this land application system is more related to sludge than to sewage effluents, but its long and successful experience confirms the feasibility of that method of land application of wastewaters. There is a non-technical 16 mm color film, entitled, *Wealth from Waste*, which shows the Herefordshire operations.

Guidelines for Implementation of Land Application Systems - Section VI

The survey provided many guidelines that could be translated into "do's" and "don'ts" in land application procedures. In addition the literature searches brought added criteria to light, confirming the basic facts evolved from the survey. From these information sources and others, the report suggests guidelines for the implementation of land application systems.

For the guidance of the regulatory administrator staffs, decision-makers, designers and owners of future land application installations, some tentative procedures have been presented as they may be affected by climatic meteorological phenomenon; availability and location of land areas suitable for wastewater application; rates of application; types of soils, crops and ground cover; methods of application and their relationship with geological, topographical and hydrological conditions; types of wastewater pretreatment to assure proper and safe land application; capital and operating costs; monitoring and health protective measures; and other related aspects of system planning and execution.

References have been drawn from all possible sources to support the tentative parametric procedures outlined in the guidelines. The listed criteria are not presented as "standards"; this would be improperly anticipatory of the next official step which must be taken to distill from this study and the other parallel investigations sponsored by the United States Environmental Protection Agency on land application techniques. Rather the guidelines are offered as *suggested criteria*, a necessary input into the overall fund of information upon which eventual official guidelines must be based. As mentioned in the *Overview* this gives credence to the suggestion that formalization of guidelines be deferred until "interim evaluation procedures" are published.

Placing Land Application of Effluents In Perspective: An Interpretation - Section VII

This section stresses the importance of placing land application techniques in their proper perspective, and interpreting the alternative "pluses" and "minuses" on the basis of local factors and local needs.

It is evident that an "alternative" must be compared with something for which it is an alternative. Thus, the determination of the choice of wastewater utilization process must be based on a full-dimensional decision; and that decision must stem from placing the land application process into the proper perspective with itself and with other means of managing wastewaters.

When viewed in this light, land application technology is not a panacea for all wastes, in all areas, under all circumstances. It is not a "quick and easy" means of getting rid of unwanted wastewaters. It involves adequate pretreatment, effective operational procedures, rigid monitoring controls and rational cost evaluations. As a substitute for the return of waters into the drainage basins from whence it originally came, it can affect the "cycle of water" and create an imbalance in the water resources of a region. Land application can no longer be compared with disposal of wastes by dilution; just as conventional wastewater treatment now involves high degrees of treatment, so land application must assure that the soil will receive highly treated influent water or that the soil will provide the equivalent of tertiary treatment and removal of deleterious components by biological-chemical-physical phenomenon. The effectiveness of land application must be judged by what it accomplishes—not merely as a means of eliminating the direct discharge of comparably well treated effluents into receiving waters.

To fulfill its full possibilities and benefits, land application must be examined from the standpoint of what has become known as the "4-R cycle"—*return* of wastewater to the local land rather than being lost by stream flowage to downstream areas; *renovation* of the wastewater by soil and vegetative actions; *recharge* of the groundwater resources which then become the reservoir aquifer which feeds surface water sources; and the *reuse* of wastewater either directly off the land or via the groundwater reservoir. Practical examples of these land application benefits are available; they must be placed in proper perspective with the needs and potentialities of the area in which a proposed land application project will be constructed as an alternative to conventional wastewater treatment works.

Demographic Evaluation of Land Application Techniques

Demography is the science of social statistics. Wastewaters are the product of people and of industrial production in an urban industrial society. The nature of wastes produced by community life and industrial processing and the amounts of such wastewaters are affected by regional conditions and their impact on life and living processes. Automatically then, the manner in which wastewaters are handled and disposed of is influenced by demography, or regional, environmental needs. For example, the degree of sewage and industrial treatment in the past was influenced by the water resources needs of regional areas and how regulatory bodies interpreted these needs to protect the natural environment and preserve public health and safety. Over and above the natural setting for any region, policies were and will continue to be, affected by population densities, water needs, public desires and antipathies, and other factors. This represents demography in action.

If it were possible to relate the applicability of wastewater management on land areas to such factors as climatic conditions, population and population densities, economic-social patterns, and similar demographic parameters, these would serve as important guides for the choice of this alternative method of wastewater treatment and utilization vis-a-vis today's conventional treatment standards and the advanced degrees of effluent quality that will be required in the future. If such relationships could be established, based on the findings of the APWA Report, or by parallel investigations now sponsored by EPA, the viability of the land application technique could be verified or clinically questioned.

The factors involved in a full demographic evaluation of land application practices appear to be too numerous, too complex and too interwoven to be capable of clarification by the current APWA study. Many of the factors are too intangible to be explained by basic survey data; the type of study parameters used in the current study could not include such incomprehensible implications. But the study did involve the relationships between land application and climatic conditions, and concurrent relationships involving urban populations and densities, industrial operations, local ecological conditions and other indigenous factors (See Figure 1).

Climate is a major factor in the applicability of land application procedures, on the purpose and continuity of operation, and on the performance of this alternative technique. In recognition of the importance of climatic conditions, the study was based on the choice of site investigations in five climatic regions of the United States and evaluations were aimed at determining the impact of the specific zonal meteorological characteristics on every phase of the study (Figure 2).

DEMOGRAPHIC EVALUATION

1. **Climate Conditions**
2. **Size of Facility**
3. **Continuity of Operations**
4. **Methods of Distribution**
5. **Land Availability**

Figure 1: Demographic Evaluation.

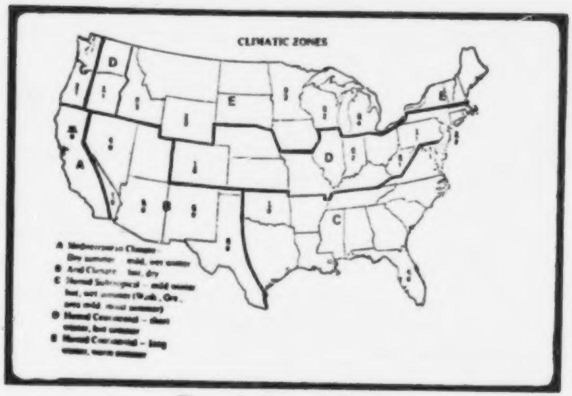

Figure 2: Climatic Zones.

Broadly characterized, *Zone A* (mid and south Pacific coast) is an area of dry summers and mild wet winters; *Zone B* (the southwest) is an arid region, with hot, dry climate; *Zone C* (southeast-Gulf coast-Atlantic coast and Pacific northwest) experiences hot wet summers and mild winters; *Zone D* (east-continent and northeast Atlantic coast) is subject to humid weather, with short winters and hot summers; *Zone E* (mid-continent and far northeast) is a humid area, with long winters and warm summers.

While climatic conditions have the most significant impact on the land application principle, other factors have potential bearing: size of the community and the industry; the volume of wastes flow; the population contributing sanitary wastes plus the population equivalent of the industrial wastes contributed to the municipal sewer system; the availability of open land for irrigation use; the land-use zoning of the region; the cost of land; the type of crops to be grown with supplemental irrigation and the market needs and demands for such crops; the groundwater depth and quantities, and their use for water supply purposes, protection against salt water intrusion into aquifers and other functions; the nature of the soil; the proximity of surface waters which can become recipients of conventionally treated effluents; and other correlated circumstances of local or indigenous nature.

It is not difficult to rationalize the effects of these climatic-demographic conditions on land application practices, and conversely, the impacts of land application on these environmental conditions. It is difficult, however, to translate the findings of the subject into these relationships. Efforts have been made to draw every possible relationship between these various factors but the findings are often too indeterminate to warrant such translations.

The following highlights can provide valuable guidance for decision-makers and designers of land application systems, even though they are not always affirmed and confirmed by study findings.

Climatic Conditions

The 67 community systems and 20 industrial land application sites covered by the on-site visits, and the comparable numbers of such installations covered by the mail inquiry, were representative of the actual total projects in each of the five climatic zones. The major number of community systems surveyed was located in Zones A and B, with California sites predominating. These two zones represent dry and arid conditions which make supplemental water resources—reused water in the form of effluents—a precious commodity. No industrial sites in these zones were surveyed by on-site investigators because minimal use of land application techniques is made by local industrial installations. In lieu of such industrial irrigation projects, communities in Zones A and B accept industrial wastes into public sewers and onto publicly owned application sites in the form of population equivalent loadings.

In Zones C, D, and E, industrial sites were surveyed because the use of land application is practiced more generally in these parts of the nation. The industries involved are primarily food canning-processing factories, dairy processing plants, pulp and paper mills, and organic chemical manufacturing firms.

The differentiation between the zonal incidences of community systems and industry sites is explained, at least in part, by the needs for supplemental water and the uses for such water. Thus, climatic water-short and water-rich areas dictate the retention of sanitary wastewaters in the areas which produce them, or whether to permit them to flow away downstream into other receiving watersheds and water basins.

In regions A and B, water is in relatively short supply, due to dry summers and year-round aridity, and wastewaters are often times considered by communities as a valuable commodity for land irrigation, for groundwater augmentation, and for use for such ancillary purposes as golf course and highway median watering and the creation of recreational water facilities. Industries in these areas however, as in other areas, are less concerned with such beneficial uses of wastewater and may not practice land application; they may use this management procedure primarily for the purpose of "getting rid" of such effluents in the cheapest and simplest manner without adversely affecting the environment.

This brings the matter of wastewater, or used water, economic and ecologic value and utilization into focus as the determining factors in the practice of land application. In arid regions, land application offers strong incentives. In wet, humid regions water-husbanding is not a vital motivating reason for land application installations; but such motivation can be found in the economies of producing high-quality effluent by means of the "free" purification capabilities of soil. Whether planned as a water resource conservation procedure or not, the ultimate fate of wastewaters applied to land areas by spray irrigation and surface application, such as, ridge-and-furrow methods is a means of enhancement of the local groundwater reservoir. The fact that 85 percent of the water stored in the United States is contained in subsurface aquifers adds significance to this wastewater fate.

Climatic, geographic and geologic conditions have other influences on the choice of wastewater disposal systems. Inland areas that have no convenient receiving waters may find it cheaper to apply wastewaters to the land rather than constructing long, expensive outfall lines from their treatment plants to suitable discharge points. On the other hand, the water-cycle imbalance which may occur in local waters by taking water supplies from them and not returning wastewater back to the same rivers and lakes may place a negative aspect on land application procedures. This type of water resource imbalance does not apply to coastal waters.

The relationship between hard winters and land application systems is obvious. In areas where full-year irrigation can be practiced, land application would have greater applicability than where adverse winter conditions would make irrigation inappropriate or inefficient. While land application is practiced in some ice, snow and sub-freezing conditions, optimum conditions are represented by year-round mild weather such as is experienced in Zones A, parts of B, and in C.

Similarly, the relationship between climatic conditions and holding pond capacities is equally understandable. Where seasonal cessation of land application is necessary, the principle of "not one drop of wastes into water resources" impells the construction and use of adequate holding facilities. "Adequacy" is a relative term; 31 percent of community and industrial systems use ponds with capacities of five days or less. In Zones A, B and C, 75 percent of the sites have holding capacities of less than 30 days, or less than needed for a full winter season. One installation in a cold zone provides a 50 million gallon pond for a daily flow loading of 0.5 mgd.

Of some significance, if not as perinent as other seasonal conditions, is the amount of rainfall in humid areas which may impede soil absorption of applied wastewaters and require the use of flow-equalization or flow-holding of excess waters until required rates of application can be reinstated. As stated, where rainfall is generally adequate, if not always predictable, land application for enhancement of crop growths, forest growths and groundwater augmentation is not the dominant reason for the choice of this wastewater management technique.

While the survey studies brought these climatic relationships into focus, they did not always provide positive proof of these effects and impacts. This does not detract from the validity of the above observations. No attempt has been made to draw all possible climatic-environmental relationships with land application principles and practices; however, the rationale is adequate to demonstrate that there is a direct correlation which must be considered before choice of wastewater management is made for each individual project. No set standards can be established; each case will require its own relationship evaluation.

Size of Wastewater Facility

In the case of publicly owned systems, the population served is translatable into volumetric and qualitative loadings. For industries, the flow loading is a factor of volume and population equivalency of the organic constituents, as measured by BOD, COD, suspended solids and other significant parameters.

The survey indicated that some outstanding large community land application installations have been in service in the United States and foreign countries. However, the major percentage of current operating installations are in the smaller-size range.

The on-site survey disclosed that 73 percent of communities studied have land application capacities of under 5 mgd; the mail survey covered no community systems with over 10-mgd capacity. Industry installations covered by the on-site survey were all under 5-mgd capacities; the mail-surveyed installations were all under 10-mgd size. It is conjectured that the small cities and industries have found land application within their economic range and that adequate conventional treatment would have been more costly.

Size factors are numerous but few showed definitive relationships with other land application site acreage parameters. The area used for irrigation application varied without basic reason from the total acreage owned by the community or industry. In some cases the major extent of the area is used for distribution; in other instances only a portion is so used, the rest of the acreage being devoted to holding ponds, buffer zone and general isolation of sites.

The size of the area varies, naturally, with the volume of flow applied, the nature of the soil and its absorptive character. The effect of climatic conditions, such as rainfall, humidity and temperature, on irrigation area acquired by communities and industries is minimal, despite any impression that such a direct relationship should exist. No specific trend was found in buffer zone regulations and usage. The open land available for such buffering or isolation facilities is undoubtedly influenced by State regulatory agency requirements and the type of distribution systems used. (Spray irrigation tends to be associated with buffering acres and plantings to impede the off-site dissemination of aerosol mists and particulates.)

Continuity of Operation

The relationship between continuity of wastewater application, on a days-per-week or a months-per-year basis, and land acreages used for land application was found to be indeterminate. Continuity of operation appeared to be dictated by other factors than availability of site acreage. It is obvious that rates of application should have a bearing on the land areas required, particularly on sites that are limited in size and not over-generous in dimensions. While the analysis of study data does not disclose this relationship, it is undebatable since the failure of irrigated land to handle distributed wastewaters for planned periods will necessitate the resting of such areas and the immediate utilization of other equivalent acreages to replace the overloaded or ponded soil plots.

If wastewater production is in effect for longer weekly or monthly periods and pond storage capacity is not available to retain excess flows, irrigation areas may be affected by the requirement that direct application of produced flows must be provided. Similarly, the land-need requirements for any site will be influenced by whether the system will function on a twelve-month basis or shorter yearly periods (Figure 3).

Climate Zone	% Year-round Community	Industrial
A	76	
B	63	
C	56	50
D	71	56
E	67	30

Figure 3: Continuity of Operation.

Communities tend to maintain yearly continuity of land application more completely than industries; broadly interpreted, communities operate full-year at 60 percent of installations, and industries at 40 percent of sites. The relationship between climate and continuity of irrigation was partially clarified by the study, despite the fact that positive patterns were not confirmed. The on-site survey-interview procedures used in the study disclosed that twelve-month continuity of community operation for Zones A, B, C, D and E was practiced in 76, 63, 56, 71 and 67 percent of sites, respectively, while industrial systems showed similar year-round irrigation service in Zones C, D and E of 50, 56 and 30 percent of sites, respectively.

The mail survey showed that industries in Zones A and B (not surveyed in the on-site program) operated on a twelve-month basis at 100 percent of the sites involved, with 100 percent of the Zone C community installations functioning on a full-year basis. Thus, the zonal factors showed little effect of widely divergent climatic conditions on whether systems functioned without cessation.

Full-week service seemed to be dictated more by the actual purpose of land application than by other factors. Full-week irrigation was found to be more common than when crop irrigation was practiced than when wastewater disposal onto grass-cover lands was utilized for groundwater augmentation or for the simple purpose of effluent disposal. Application rates and continuity of irrigation were, surprisingly, unaffected by soil types.

Methods of Distribution

The relationship between the method of application and climatic conditions was brought into focus by the study. In general, spray irrigation is more commonly used in humid areas than in arid sectors; and surface application techniques, such as ridge-and-furrow irrigation and overland irrigation, are more frequently utilized in arid regions. Zones A and B were characterized by surface application sites.

The relationship between size of site and type of distribution used showed a trend of more or less specificity. Smaller sites were served by twice as many spray systems as surface application facilities. Larger sites, over 1,000 acres in size, were usually equipped with surface application systems; intermediate-sized sites, from about 100 acres of 1,000 acres, utilized spray and surface application systems about equally. In surface application installations, so-called overland flooding which depends on sheet-flow action has been used more frequently than ridge-and-furrow distribution.

No specific correlation was found between distribution methods and soil types, but some generalized patterns were evaluated: spray irrigation is more commonly used on loam, silt and clay lands; spray and surface application methods are generally used equally on more granular soils. Surface application methods were found more frequently on crop lands or on unplanted, non-cover areas. Spray irrigation was found more frequently on crop lands and forested acreages. Community sites handling under 1-mgd flows were most commonly grass-covered, while larger areas of over 1-mgd capacity generally stressed crop growth. Forest irrigation was practiced more frequently in humid areas than arid regions, probably because tree growth is more common in the humid climatic regions. Cropping on arid region lands is relatively common, indicating the value of wastewater for supplemental irrigation.

Groundwater depths are a dominant factor in choice of sites but, once acquired, these application lands experience minimal impacts on choice of application methods and on operation performance. Obviously groundwater depths are greater in arid regions and are less of a factor in choice of land application sites. Application rates, while not consistently influenced by climatic conditions or soil character, and while varying minimally from the almost traditional level of one-half inch per day and two inches per week, are influenced by aridity and high humidity-precipitation conditions.

Land Availability, Land Use and Land Value

A direct relationship between demographic criteria and land availability, zoning use and acreage price is unavoidable. The first requirement of a land application system is *land*. It must be available in reasonably close proximity to the source of community or industrial wastes; the land must be useable for wastewater application by zoning and other use regulations; the price must not be prohibitive.

These conditions are most commonly met in areas of low population density where open lands are available, and where undeveloped and properly zoned properties can be acquired at relatively low cost. This is why the survey showed the predominance of land systems in use by small communities and relatively small industries, and land prices ranging basically in the under-$500 per acre price level. Areas of the nation will become progressively more densely populated because over a million acres of rural lands are absorbed annually in urbanization and related facets of community growth. The availability of nearby lands, zoned for agriculture or residential purposes, and priced at low enough levels, will become a greater problem for users of land application systems. The cost of long-distance wastewater transmission will become an important factor in determining the economic feasibility of land application for wastewaters.

The impact of land application installation on neighboring areas and their residents can be in direct ratio to population density. While existing systems have demonstrated their ability to be "good neighbors" to residents living as close as 500 feet of application site, this close proximity may not be good practice in all cases. Reported complaints have been minimal against present installations despite the fact that, for example, 20 percent of community systems in Zone A are located less than 500 feet from the nearest neighbors and 22 percent are similarly located in Zone B. Industrial sites are located in Zones C, D and E within 500 feet of residences in 10, 10 and 21 percent of the cases investigated, respectively.

The relationship between local demographic conditions and land application system monitoring is obvious. The degree of monitoring was found to be less related to zone climatological conditions than to State health and water pollution control regulations in the limited cases where such governmental stipulations are imposed. It is understandable that increasing population intrusions in an area, and the density of the residential population, will dictate that closer attention should be given to the impacts of land application on land and water resources and on persons exposed to actual wastewater, sludge residues, spray mists and animals and insects which come in contact with irrigation liquids and vegetative growths. The frequency and location of monitoring points, such as test wells and other sampling facilities, and the extent of monitoring parameters will be intensified in the future to satisfy actual hazards or the psychological impressions of local residents.

Site security measures, such as fencing may be required and buffer zones may be specified. Operation and maintenance costs will react to all such monitoring and security requirements but the reasonable cost levels for present systems could be increased without seriously affecting the feasibility and economy of land application techniques. Future wastewater treatment works, particularly those requiring full secondary treatment and processing to remove such components as phosphorous, nitrogen, trace metals and organic pesticides, will require similar augmentation of present specific laboratory control and site safety and security measures.

Fate of Materials Applied to the Land

To complete this extended summary of the land application of. wastewaters a review of the fate of applied materials is presented to round out the information which has been presented. Reference is made to two papers entitled, *Experiences with Land Spreading of Municipal Effluents,* and *Fate of Materials Applied,* prepared by Richard E. Thomas, Soil Scientist, Robert S. Kerr, Water Research Center, Environmental Protection Agency, Ada, Oklahoma. For the future applicability of land utilization of wastewaters, it is important to know with some measure of certainty what the fate of wastewater components will be.

The materials contained in wastewaters are reminiscent of the origin of these flows—either sanitary, sanitary and combined storm water, industrial process water, or combinations of sanitary and industrial wastes. Since the application of raw wastewaters onto land areas is not contemplated under the definition of this alternative waste management technique, all such wastes have been subject to some degree of pretreatment before they are applied to land. The purpose of monitoring of influent flows onto land areas is to ascertain the composition of the wastewater *after* the stages of pretreatment provided.

A classification of wastewater materials could be: *suspended materials;* major plant nutrients; and other constituents. Another delineation of the wastewater components, based on the actual physical nature of the substances is: *suspended solids;* colloidal solids; dissolved organic materials; and dissolved inorganic substances.

The fate of these substances during the process of land application will vary with the type of distribution system, the nature of the soil, the rate of application, the climate, the resting periods, and the location and proximity of the groundwater aquifier and the surface water source which receives runoff from the site. The phenomena involved include: the physical condition of entrapment or mechanical filtration; the biological, biochemical, electrochemical and other manifestations in and in contact with the soil; evaporative factors; atmospheric oxidation; bacteriological, germicidal, and bacteriophage or anti-contamination reactions, and others which are not totally understood even by highly trained and experienced scientists.

Suspended solids entrapped in the interstices of the soil or adhering to soil particles by electrochemical entrainment can experience biological oxidation and decomposition into stabilized substances. The fate of this suspended material can vary; it can remain in the soil to form humus soil conditioning or nutritive material or, in course media, it may be sloughed off and percolated into lower soil depths or into the groundwater.

Colloidal materials—solids of minute size which may be able to filter through soil media—can be coalesced or coagulated by electrochemical agglomeration and then adsorbed onto soil particles. The fate of this material, normally considered to possess electrical charge, may parallel that of true suspended solids, by oxidation-digestion phenomena. Accumulations in the soil may affect the rate of application of subsequent wastewater loadings.

Organic dissolved solids may be utilized by plant crops, retained in the body of the soil by chemical fixation or other bonding phenomena or may be oxidized by atmospheric reactions, in the course of air contact with sprays or sheets of wastewater flowing over the land.

A major concern is centered on the nitrogen and phosphorous in wastewaters. The presence of these dissolved constituents can influence the use of land application systems in lieu of advanced treatment and discharge into surface receiving water, primarily because they can act as "triggers" in the eutrophication of surface waters. Similarly, if these materials can adversely "fertilize" lakes, why cannot they be used to fertilize land?

The fate of nitrogen and phosphorous will be influenced by many factors, including the type of wastewater distribution system utilized, and the type of ground cover and crops grown. The factors involved in the different land application methods are covered in excellent details in the above-referenced papers, and it is not the intent here to explore these manifestations beyond brief reference to the fact that the fate of these two basic elements can be regulated by proper practices to avoid serious effects on groundwater or surface water sources. The ability of soil to retain and fix phosphorous delivery to the soil may be greater than the crop uptake ability to utilize it. Fortunately, soil retention is able to prevent phosphorous intrusion into groundwaters that are adequately deep for any effective land application site.

Nitrogen could enter the groundwater in concentrations that might exceed the safe levels of this material in water for human consumption. However, the ability of land application techniques to complete a nitrification-denitrification cycle can be utilized to prevent this fate, as in the spray-runoff technique. A substantial proportion of the phosphorous contained in applied wastewaters in the same spray runoff process could reach surface water sources unless steps are taken to improve phosphorous removal by land contact.

Other constituents of land-applied wastewaters have fates that may influence the use of land methods, either in favor of this alternative process or opposed to its utilization. These include heavy metals, even in trace amounts, pesticides and other organo-compounds, and various salts. Evaporation and evapotranspiration of liquids from soil, vegetative surfaces or water surfaces will not change the fate of these dissolved materials; the evaporative process parallels the distillation phenomenon, in that the water is converted to vapor or gaseous form and the solids are thus concentrated in the soil or vegetation. Salts may thus reach the groundwater by percolation and leaching action. Heavy metals and pesticides can undergo physical, chemical and biochemical interactions with the soil, making land application an auxilliary means of providing so-called "tertiary" treatment for wastewaters, in lieu of more complex and more costly artificial wastes treatment processes.

To repeat the statement made above, the intent of this dissertation on the fate of materials applied to land areas is to point out that the soil and vegetative forms do offer a "bonus" factor that must be given consideration in determining the future of the land application process. Current concern about the impacts of nitrates, phosphorous, trace metals, pesticides and other organic compounds on receiving waters is sufficient reason for knowing more about the fate of these objectionable materials in the land application process. More remains to be known about them, and about the way various methods of wastewater distribution, various types of soil and topographic and climatic conditions, and other factors and combinations of factors, influence their fate.

The fate of wastewater contaminants during the land application process, in short, offers opportunities for beneficial use for soil and crop enhancement which must be considered as a "plus" for this alternative technique. In addition, the capability of the land application system to remove, modify and stabilize pollutants which would require augmented processing in conventional sewage treatment systems offers another advantage for this alternative management procedure. But, these benefits must be evaluated in the light of whether the applied materials will in any way adversely affect the water and soil environment of the region where land application systems will be utilized. Only through a weighing of the benefits and hazards can the feasibility and applicability of land application processes be properly judged for each specific installation and each specific wastes problem.

CONCLUSIONS

1. *Land application of wastewaters from community and industrial processing sources is practiced successfully and extensively in the United States and in many countries throughout the world.* Facilities investigated handled from less than 0.5 mgd, providing service for sixty days per year, to over 570 mgd applied on a year-around basis.
2. *Land application of wastewaters is practiced for several specific reasons.* Among the major reasons were: to provide for supplemental irrigation water; the desirability of augmenting groundwater sources; excessive distances to suitable bodies of receiving waters or extraordinary cost to construct facilities to reach suitable disposal sites; economic feasibility, as contrasted with the cost of construction and operation of advanced or tertiary treatment facilities; inability of conventional treatment facilities to handle difficult-to-treat wastes.
3. *Present land application facilities generally are not "stressing" the system.* Many facilities were found to be using effluent on a crop-need basis. Even where efforts were being made to use land as the only point of disposal, application rates were generally conservative and the soil-plant components of the system were not stressed to limits of assimilation or used to their optimum capacities, thus providing a large factor of safety.
4. *A variety of beneficial uses are being made of wastewater effluents.* Uses include irrigation of parks, golf courses, cemeteries, college grounds, street trees, highway median strips, sports grounds, ornamental fountains and artificial lakes. Wastewater effluents are also used to irrigate many types of crops, including grasses, alfalfa, corn, sorghum, citrus trees, grapes, and cotton. Forest lands are also being irrigated in many areas. Groundwater augmentation to prevent salt water intrusion is being practiced. In Mexico, a wide variety of truck garden crops has long been irrigated with effluent. Crops appeared to benefit from both the nutrients and the increased amount of water which is applied.
5. *A large variety of potential opportunities for land application of wastewater exist in many communities.* Wastewaters that are given a high degree of treatment could well be considered for irrigating large public and private facilities to relieve the demand for irrigation with potable water supplies. Golf courses, cemeteries, parkways, school grounds, parks, airports, planned unit developments, green belts, forest preserves,

and marginal land all offer the useful application of effluents to the land.

6. *Sale of effluent for beneficial use has been generally unsuccessful.* Few examples were found where a public agency had been able to obtain more than a token payment for supplying treated effluent. In several cases it was reported that land for the treatment plant had been given in consideration of a right to all or a portion of the effluent. Where an agency received a tangible dollar return, it was generally based upon use of both land and the effluent.
7. *Successful operation of a land application system requires the inputs from a variety of disciplines.* For many systems, the services of a geologist and environmental engineer are required. For system designed to augment the indigenous crop water requirements by supplemental irrigation, the advice and guidance of soils specialist will be needed. For larger systems, social and behavioral scientists, as well as medical-health personnel may be required to assist in evaluating and securing acceptance of this alternative means of disposal.
8. *Operation of land application facilities can be accomplished without creating a nuisance or downgrading the adjacent environment.* The survey indicated that a majority of the facilities were conducted by well-trained personnel, aware of the need for careful operation of the systems. Training, supervision, and adequate monitoring of pertinent factors are necessary to ensure that systems will not be over-stressed. If ponding on the land is not allowed, odors will not be a problem. The hazard of creating other adverse effects on the environment by discharging treated effluent on land is minimal.
9. *Monitoring of land application facilities and effects has been minimal and mostly inadequate.* Few states appear to have taken an active role in requiring use of monitoring facilities, apparently because there was no direct discharge of effluents to receiving waters. Many of the municipal systems surveyed had little or no monitoring, inasmuch as the effluent was being used only for supplemental irrigation.

   Industrial systems were generally better monitored, but control in most cases cannot be characterized as being adequate.
10. *Environmental analysis of the effects of land application facilities reflects a general improvement of the environment rather than impairment of the indigenous ecology.* Many facilities were observed where the effluent provided the only irrigation water available. Land values for sites with a right to such waste waters were greater than that of adjacent land because crop and forest growth was enhanced, and use of potable water supplies reduced. No instances of health hazards were reported from any existing facilities, although the State of Delaware indicated concern over potential virus transmission. Farming and recreation potentials exist, as well as improved habitat for wild life.

    Treatment of wastewater prior to land application has generally been dictated by the desire to use the best practical means consistent with available technology and to minimize any adverse effects upon the environment. Land application of wastewater, by eliminating direct discharges of effluent into receiving waters, could be regarded as satisfying the ultimate national policy goal of "zero discharge" of pollutants.
11. *Energy requirements for land application systems may be an important consideration.* Reported energy requirements for most advanced tertiary treatment proposals are very high, as compared to conventional treatment. Depending upon the location and availability of land, energy requirements associated with land application techniques may be substantially less than other means of treatment and effluent management. This factor deserves further evaluation.
12. *The nature and quantity of receiving waters must be carefully evaluated prior to diverting effluent to land application.* Few existing systems were found that used underdrains to collect the renovated effluent. Rather, the groundwater aquifers received the flow. If a land application area is adjacent to the receiving water, much of the groundwater may serve to augment the flow into the receiving waters by a gradual seepage into the drainage basin. Elimination of direct wastewater discharges to a stream could unbalance the flow regimen associated with downstream beneficial uses, inhibit desirable dilution of waste discharge, interfere with the tempering of thermal water discharges. Land application can prevent the intrusion of saline waters into normally fresh water zones. The impact of effluent diversion onto land areas with respect to the basic principle of riparian water rights must be considered where irrigation is planned as an alternate to discharge into surface waters.
13. *When wastewater is discharged to land and this method is used as a means of advanced treatment by natural means, the land must receive priority for this use over other optional land uses.* The needs of crop production, recreation and other benefits can be in conflict with the utilization of a land application system for the treatment of

wastewater. For instance, the planting, cultivation and harvesting of crops and the use of recreation facilities may interfere with continuous application of wastewater onto land areas. The need for the system to either utilize all of the flow or provide sufficient retention storage for needed periods of non-operation must be provided. The objective of providing adequate treatment of the effluent can not be sacrificed for other needs and uses of the land; proper handling of the wastewater must be the first priority.

14. *Choice of ground cover can play an important role in the success of a land application system.* On other than sandy soil, it appears that forested or minimally wooded or cultivated areas will accept greater rates of application of effluent without ponding than will cultivated agricultural areas. Many existing facilities utilize forest areas and grassed areas for application. Forested areas appear particularly useful for winter applications when fixed spray systems are used. Reed Canary grass appears to be particularly well suited for producing mulched ground cover which can enhance soil assimilation and absorption characteristics.
15. *Land application facilities that have been used for many years are available for the study of long-term effects of such use.* They offer the opportunity to study effects on soils and groundwaters. Thus, it appears unnecessary to support separate demonstration facilities in each of several states and regions. During the course of the study project, several small-scale research and demonstration projects involving land application were disclosed. Some of these projects appeared to have been instituted simply for the purpose of convincing local and state officials of the safety of this alternative method of treatment and disposal. Specific evaluation at established systems in the various climatic zones would appear to be more fruitful than new research installations for determining long-term effects upon soil, vegetation, groundwater, and the indigenous ecology, or on the health of site workers and adjacent residents.
16. *Observations in the field and the survey of land application systems which handle municipal wastewater flows and industry-owned systems which handle process waters did not reveal the existence of specific health hazards and disclosed very little concern over threats to the health of on-site workers, residents of neighboring areas, domestic animals or wildlife, or of those who consume or come in contact with land-applied wastewaters.* The mail survey of other representative municipal and industrial land application systems similarly provided no evidence of any health problems associated with this method of utilization.

Some concern over potential health hazards was, however, expressed or inferred by officials of some state agencies, who supplied information about their policies on land application of effluents as an alternative means of wastewater management. Whether this concern was based on specific information or mere suspicions, founded or unfounded, could not be determined from their response.

Inquiries have been made with inconclusive results about the health implications of land application systems by several Federal state and local agencies, and by other quasi-governmental and public service organizations. Concern over "the unknown" was expressed for such factors as potential viral and pathogenic hazards resulting from dissemination of aerosol sprays or mists and contacts with sanitary and industrial sludge residues.

While the study did not disclose the cause for such concerns, the bibliographic abstracts* prepared as an integral part of this investigative project do include references describing possible health hazards which warrant further study and these potential problem areas should certainly not be ignored.

A balanced consideration of the concerns, and of the absence of any study evidence to support these questions, would be of great value at this time.

RECOMMENDATIONS

1. *Guidelines for land application of wastewaters should be prepared by the U.S. Environmental Protection Agency to provide full consideration of the wide choices of available methods and procedures.* Guidelines should be prepared in a manner which will not restrict unduly the ability of local officials to make full use of this alternative method of treating and managing wastewater.

2. *Land application must not be considered as a panacea or universal method of treatment.* Suitability of each land application system can only be determined as a result of an interdisciplinary study for the particular site. Soils, climate, degree of pretreatment, groundwater conditions and availability of suitable land acreages are important considerations.

3. *Preparation of a suitable publication to inform the public about the practice of sewage effluent on land should be sponsored by the United States Environmental Protection Agency.* Public relations problems are usually encountered by agencies attempting to implement any large public wastewater

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* The bibliography for the APWA report is being published separately, entitled, *Land Application of Sewage Effluents and Sludges: Selected Abstracts.*

project. Recent efforts to consider land application as an alternative in planning for regional approaches to wastewater management have highlighted the need for such publication.

4. *Training opportunities should be provided to bring to the attention of all disciplines involved in the consideration and evaluation of a land application facility the technical information which is available.* Widespread consideration and utilization of land application cannot be made until such time as adequate information concerning the technique involved is made available. The experience gained by those who have successfully utilized this wastewater management method should be publicized.

5. *Guidelines for the increased use of land application methods, which could result from the implementation of Section 201 of the 1972 Amendments to the Federal Water Pollution Control Law and its emphasis on alternate wastes management techniques and systems, should clarify the question of whether health hazards are a factor in the use of this system of treatment and disposal.* Definitive findings are essential to the acceptance of land application systems, or to their adoption for municipal or industrial effluent management. Such findings should be provided with promptness and clarity, either through evaluation of existing data or any additional necessary research. Without such positive information, published guidelines might either be inadequate or tend to be too restrictive. If they are too stringent, this could endanger the proper utilization of land application systems as effective and economical solutions to water pollution control problems and the rational use of wastewater for crop and groundwater enhancement and other environmental-ecological benefits.

Some Experiences In Land Acquisition for a Land Disposal System for Sewage Effluent

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ABSTRACT

The paper attempts to deal with some of the experiences in implementing the Muskegon County Wastewater Management System in the areas of land acquisition and relocation. No effort is made to include any other facets such as the technology involved and costs. We have set forth some of the considerations which must be addressed in early planning in connection with putting together large tracts of land including legal phases and the political acceptance.

This paper describes many of the problems which may be encountered in any location in the country where land must be acquired for the ultimate disposal of waste, both liquid and solid. In addition, we have tried to set out the advantages which can be derived from the well planned multiple usage that such a site is capable of providing. These include possible power generation, either nuclear or fossil fueled stations, the incentives for industrial expansion in the proximity, improved wildlife population, recreational potential as well as the agricultural advantages that are to be attained through the exploitation of a "resource out of place."

In summary, we have repeatedly advised the necessity for a well planned public relations program, initiated at the earliest possible moment, to provide information to the community and its leaders as well as for the people who will be subjected directly to the acquisition and relocation programs.

INTRODUCTION

This paper describes the experiences of the County of Muskegon in establishing a sewerage system to serve a metropolitan area composed of seven cities and seven urbanized townships. It covers the social, political, economic, and miscellaneous problems encountered by the County Board of Commissioners in establishing the System with emphasis on the problems relating to land acquisition and relocation of individuals, families, farms and businesses in a site area covering over 10,000 acres for the disposal site.

The writers recognized that many of the problems encountered by the County may not be applicable to other municipalities which consider utilizing the land disposal concept. However, the writers can best speak from their own experiences and it is hoped that some of the problems encountered and the solutions may be helpful to other municipalities in avoiding some of the difficulties encountered by Muskegon County.

One last comment before beginning our discussion: Although the readers will note that many diverse problems were encountered by the County, they were all solved, and the system is now in operation. Muskegon County had never been previously noted for any peculiar abilities in problem-solving by municipal cooperation. Bluntly speaking, the political fragmentation of a County of less than 160,000 persons in sixteen townships, seven cities, and two villages, coupled with multiple other overlapping municipal-type units, such as school districts and the like, made many problems inevitable and unavoidable.

This paper deals with the problems encountered by the County of Muskegon in establishing the land acquisition phase of the System. Other problems which confronted the County were of course, numerous, but are outside the scope of this paper. Rather then dealing with the constraints topically, we feel this discussion will be more meaningful and understandable by discussing the problems in sequence. Thus we will begin with the initial planning stage, implementation planning, initiation of action and execution of the plan through construction.

The project was partially funded by the Environmental Protection Agency, with a 55 percent construction grant and the State of Michigan Water Resources Commission with an additional 25 percent. The remaining 20 percent of the eligible construction costs were provided by a local bond issue.

The project has also been awarded one of the largest single Research and Development grants in the EPA's and its predecessor's history.

Description of the Muskegon Land Disposal System

Our discussion can best be followed after a brief description of the Muskegon Wastewater Management System which recycles municipal effluent on the land.

The System is designed to serve 14 municipalities or, as they are termed by the County Department of Public Works, contractees. These 14 consist of seven townships and seven cities. Six of the cities have extensive existing collection systems, while the remaining city and the townships that do not have existing facilities are now in varying stages of engineering design. The county system provides access points at which each of the contracting units may introduce their respective flows into the collection portion of the county system.

In reality, there are two complete sub-systems that make up the plan. In the north part of the county, a facility is constructed to serve the cities of Whitehall and Montague and the Township of Whitehall (Figure 1) while in the lower part of Muskegon County a vastly larger system serves the cities of North Muskegon, Muskegon, Muskegon Heights, Roosevelt Park, and Norton Shores, along with the Townships of Muskegon, Laketon, Dalton, Egelston, Moorland, and Fruitport (Figure 2).

After the wastewater is collected from the contracting municipalities and delivered to a central main pumping station, it is transported through approximately 12 miles of 66-inch concrete force main to the aerated treatment lagoons, and after this conventional treatment, is passed to storage lagoons. These storage lagoons are sized to provide a minimum of five month's wintertime storage capacity for the design flow of 36 to 40 mgd. During the irrigation season, the treated wastewater will be drawn off, chlorinated, and pumped to 57 individual center-pivot irrigation machines, most having a radius of 1300 feet, for land application.

The machines, or rigs, are basically designed as those used in agricultural irrigation and are modified to provide low-pressure, downward-directed spray. The irrigated area is sized according to the estimated nutrient content of the wastewater and the ability of the crops and soil to provide the necessary uptake and reduction. The maximum application rate is set at four inches per week, including rainfall. Normal operation will more likely be about two inches per week.

Total area under the rigs is almost 6,000 acres, which will be farmed with forage-type grasses and corn to start. The monies derived from this extensive farming operation will be used to offset the operation and maintenance costs. It is generally felt that this system provides the opportunity to hold or reduce the total cost while providing an effluent of a quality superior to that obtainable by any other treatment system and will also convert or recycle a great amount of the waste nutrients through the crop production.

After passage through a minimum of five feet of this sandy soil, the water is collected by an underdrain system, consisting of small-diameter, perforated plastic pipe covered with a close mesh nylon sleeve to prevent sand clogging. These underdrains are at roughly 500 feet centers and lead to larger concrete main drain lines. The collected underdrain water is then conducted to the main outfall ditches where, after careful quality monitoring, it is discharged to the natural waterways. It is anticipated that this water quality will meet or exceed the Public Health minimums established for drinking water.

Initial Planning

Any municipality which contemplates utilizing the land disposal technique for sewage effluent must develop careful and thorough plans for land acquisition with heavy emphasis upon public relations. Planning is, of course, essential in any municipal project, but the land disposal concept demands especially careful advance planning, because of the lack of general understanding.

If we were requested to single out the main lesson to be learned from the Muskegon project, without hesitation, we would cite the problems of developing sound public relations. Although the system was based upon several widely used processes, they had not been previously integrated for the system of waste disposal on the scale involved in the Muskegon system. The general public, therefore, had the idea that the project was new, and its components were untested and untried. While the wastewater management industry readily recognizes that land disposal is not new, we found the general public to be suspicious and extremely credulous of the system and the imagined danger to their health, safety, and welfare. Some examples will later be cited to illustrate these public doubts. Although we will discuss these experiences later in this treatise, we wish to underscore the critical importance of public support and understanding. These will be largely self-evident as we discuss our experiences.

The selection of a proposed site for land disposal is the obvious first step and the various technical considerations which are involved are outside the scope of this paper. The municipalities' engineers will have to make studies and gather data on the potential sites for the land disposal area. The determinations made by the planners and engineers will involve the topographic features, soil composition, drainage, and the like.

The technological attractiveness of a given area cannot, however, be given primary consideration for many reasons, since site selection cannot be determined in the laboratory or on the planner's table. Present land use is of critical import in the selection process, since public acceptance and cooperation will be substantially enhanced by selecting a site which is not being ideally utilized. Public understanding is achieved somewhat more easily when land reclamation can be claimed as a benefit to the sewerage disposal system.

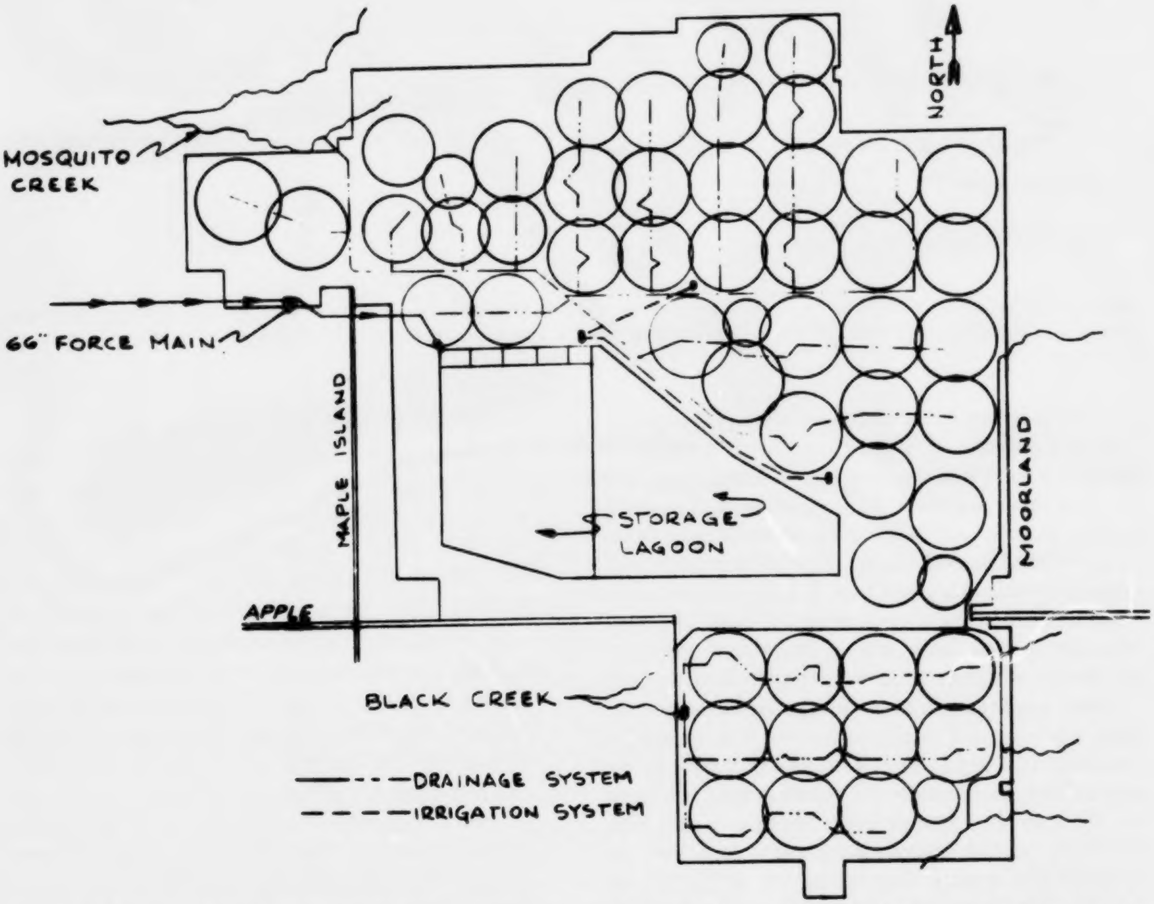

Figure 1: Sub-System in the North Part of the County, Constructed to Serve the Cities of Whitehall and Montague and the Township of Whitehall.

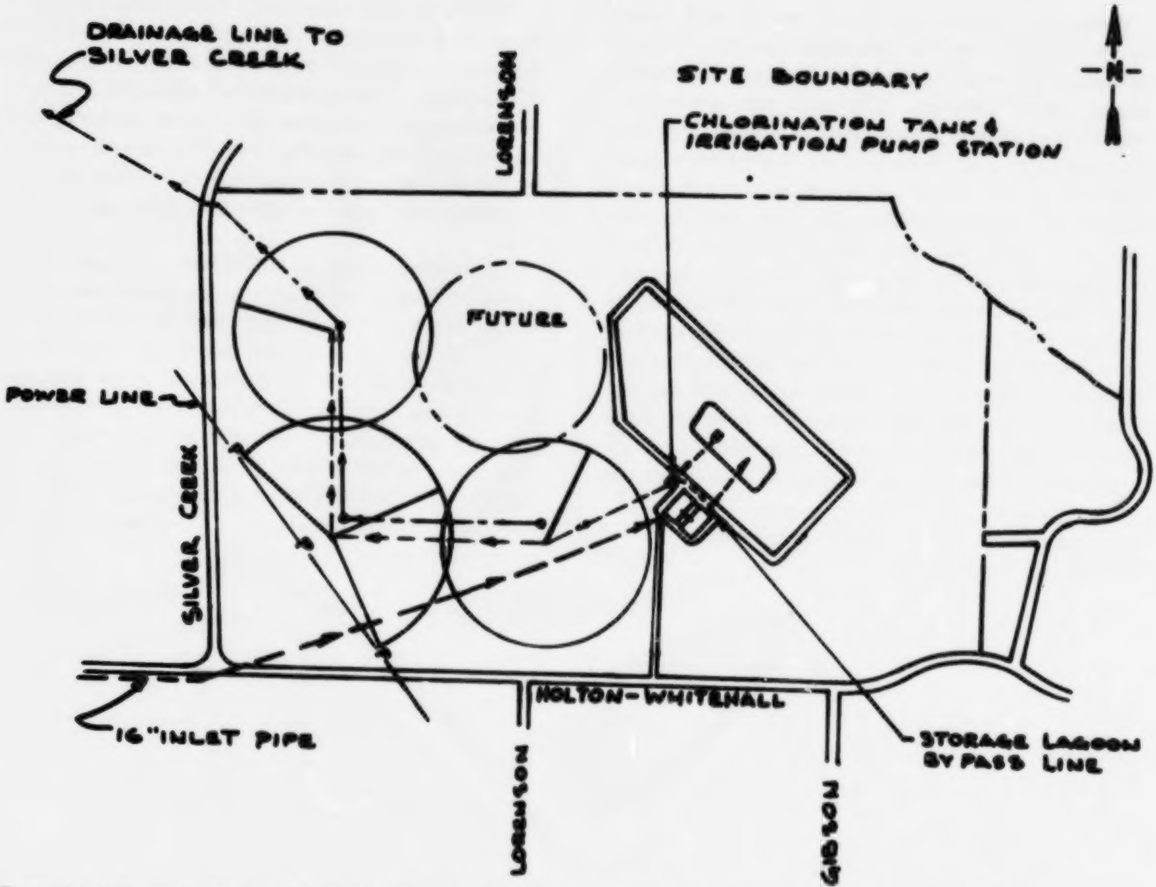
DRAINAGE LINE TO SILVER CREEK
SITE BOUNDARY
N
LORENSON
CHLORINATION TANK & IRRIGATION PUMP STATION
FUTURE
POWER LINE
SILVER CREEK
HOLTON-WHITEHALL
16"INLET PIPE
STORAGE LAGOON BY PASS LINE
LORENSON
GIBSON

Figure 2: Sub-System in the Lower Part of Muskegon County, a Vastly Larger System Serves the Cities of North Muskegon, Muskegon, Muskegon Heights, Roosevelt Park, and Norton Shores, Along with the Townships of Muskegon, Laketon, Dalton, Egelston, Moorland, and Fruitport.

Another prime factor to be considered in site selection is economics. Marginal land areas usually are sparsely settled, and thus in addition to the lower cost of lands, there are fewer families, farms, and business to be relocated. All of these matters obviously must be considered in establishing the economics of a land disposal system in a given area. It is also important to consider such costs in comparing the costs of a land disposal system with the conventional primary, secondary, advanced, and tertiary treatment systems.

Other important factors in site selection involve both legal and political constraints. It is, therefore, necessary that legal counsel be engaged early in the proceedings to research the various legal problems which may be encountered in any given site. Problems such as municipal consent to allow the location of a sewage disposal facility within its territorial jurisdiction are a major obstacle where the facility is to be located in an area outside the municipalities which it is to serve.

In the Muskegon experience, we were faced with an express statutory prohibition against locating any treatment or disposal facility within any municipality without a written consent from such municipality. (Act 185 of P.A. of M.S.A. 5.570 (10); 1948 C.L. 123.740). Since the area to be served included the major metropolitan areas, a consent in the form of a contract, was necessary to permit the location of the facilities in the rural areas. Fortunately, the township boards of the three townships did adopt resolutions and contracts permitting use of sites in their area.

In Michigan, the affairs of a township are governed by boards of trustees of either five or seven members who are elected to office. Since they must face future elections, they are obviously sensitive to the wills of their constituents. Thus, careful and thorough public relations are essential.

Politicians in our area had a clear demonstration of the effects of an aroused public, since the Township Supervisor (the Chief Executive Officer) of one of the more populous townships was recalled from office, because he led the township board into granting such a consent. Petitions were circulated to force an election, and he was recalled from office by a wide margin of votes. The central issue precipitating his recall was his leadership in approving the township's participation in the System.

Another legal and political problem we encountered which may be applicable in other areas, involves the legal ability to acquire publicly-owned lands under the power of eminent domain. Specifically, in Michigan, a county has no authority to condemn property owned by a constituent municipality for a public improvement. This legal disability is very serious and may prove to be more serious than the municipal consent problem outlined above. Michigan retains the last vestiges of a pure democracy. Its elected township board does not have the power to sell or convey real property without a vote of the electors. Thus, even if the township's board of trustees has the political courage to adopt a resolution of consent to the location of a facility within its boundaries, the electors may be able to deny consent to sell or convey the lands. Since they cannot be acquired under the power of eminent domain, the property cannot be acquired without either obtaining such voter authorization or a statutory amendment granting such powers to a municipality. Electoral consents obviously involve public acceptance and understanding and again point to the need for sound public relations. The legislative process to obtain legal authority for one municipality and even the state itself, to condemn publicly owned lands, is lengthy and precarious. In Michigan, the State Highway Department has often been stymied in attempts to acquire such lands for roadways. Its attempts to obtain legislative relief have not been successful, which shows the rather dim prospect in removing this legal deficiency.

It is critically important, therefore, to have a thorough search as to the legal title to the property which must be acquired for the disposal site. This must be accomplished before the final site is selected and the actual site engineering begins.

In the Muskegon project, we found that all three of the townships where the sites were to be located, did own a substantial amount of property. In addition, two of the school districts had acquired lands for various purposes. The same legal disability was applicable to the schools. To compound the problem, we found that some of the lands were owned by both the state and federal governments. There was no likelihood that a county would be able to condemn such lands.

It is, thus, imperative to research the title to the disposal site area in order to discover these legal deficiencies as soon as possible. The consent to such acquisitions by local, state, and federal officials can be a long and expensive process, so a very careful assessment of the likelihood of obtaining such approvals should be made as soon as reasonably possible.

Lest the readers be discouraged by the above legal deficiencies, we hasten to point out that Muskegon County was able to obtain such consents to the sale of the lands from the municipalities, schools, state, and federal governments. The techniques used to obtain such approvals were varied and will not be here discussed because of space limitations. The township electors did consent, however, in spite of the poor job of public relations for the entire project. These are discussed later in this paper. In spite of the poor atmosphere in which these consents had to be presented, electoral approval was given.

There are a number of other legal and political problems involved in any project which required the acquisition of about 10,000 acres of land. Zoning may present legal problems in certain states and areas. If it is a problem, public hearings may be necessary in order to change the zone. Legal issues on the authority of a municipality to zone against a public improvement must be carefully researched.

If roads are to be closed in the site area, the legal and political problems involved must be thoroughly investigated. Public hearings are often required in such closure proceedings, but they may also be avoided by certain techniques in each state. We overcame the problems in Muskegon without public hearings, but if such public hearings are required in other states, it is obvious that good public relations are essential.

A practical consideration which may involve both legal and political judgements is the proximity of schools, churches, cemetaries, and even Indian burial grounds. Even though one may be able to condemn school buildings or churches, the political advisability of instituting such an action is worthy of careful consideration. Anyone who has been involved in attempting to relocate a cemetary or an Indian burial ground can relate the emotional problems which result. A public hearing is inevitable in such matters whether or not the law requires such a proceeding.

In the Muskegon project, two cemetaries were excluded from the site area. Fortunately, they were on the perimeter of the main site, so it was easily handled. The problems of encountering Indian burial grounds in a site area may appear minimal, but we can testify that even the possibility of disturbing suspected Indian mounds, presents very real and serious problems. In the instant project, someone claimed that there were Indian mounds in a part of the site area. As soon as that was announced, even though there was little foundation for such suspicions, we were visited by local tribes and the State Commission on Indian Affairs. Fortunately, this area was again on the perimeter of the site, so an engineering change was effected to eliminate the area, and thus, the area was excluded. Later, thorough investigation revealed that there were no Indian burial grounds in the excluded area, but the question had become moot by the time the determination had been made. Suffice it to say that if the area had been critically needed for the project, construction would have been delayed and considerable additional expense would have been involved until it was determined.

We, therefore, recommend any future planners to research the disposal area to ascertain whether there are any national monuments or other historical memorabilia within the proposed site.

If there are public utility easements in the area, serious legal and economic problems may be encountered if such facilities must be relocated. Fortunately, the Muskegon engineers were able to locate the facility so that relocating was confined to two high-pressure gas lines and some power lines.

We also encountered a number of private easements for local industries which were no longer used. The existence of such easements could also present other legal and economic implications. These easements can all be disclosed by an early title search.

Another problem that may present difficulty is that of oil, gas, and mineral rights. In the Muskegon disposal area, many of the property owners had executed leases of the fluid mineral rights. Some of such rights were reserved in old conveyances, and the State owned some of these rights. Thus, we were presented with the problem of valuing such rights and, indeed, determining whether the County could legally force the condemnation of such leases and rights under the power of eminent domain.

All of the above considerations are important in the selection of the proposed site.

If one can contain the site within one municipality, the problems of dealing with multiple municipalities can be reduced. The necessary consents to location and authority to sell lands are more easily handled when dealing with just one municipality. Substantial savings in time can also be effected.

After considering these legal and political constraints, a review of these problems and their prospect for favorable resolution must be assessed. The public relations agency should be involved in the above process as well as the engineer, planners, legal consultants, and other technical personnel.

Time may also be of the essence, so consideration must be given to the statutes which grant authority to acquire lands under the power of eminent domain. In Michigan, we found that the law was deficient in granting authority to obtain legal title and possession prior to establishing the amount of just compensation. We found that the state and county highway departments could take advantage of "quick-take" provisions whereby the condemning authority could file suit to condemn and post the amount of estimated compensation with the Court and title and possession of the property would vest in the County, unless the property owner contested the issues of necessity.

Timing is always important for any project, and the large land areas needed for land disposal are certainly not an exception. The absence of the "quick-take" provision for a public health project was deemed serious. The County, therefore, mobilized all available forces to persuade our local legislators to introduce such legislation to empower the county or any other municipality to enjoy the same advantage of the early possession of the property. After a herculean effort, the County was able to get an amendment adopted to a state law to enable the County to avail itself of this remedy. The legislation was not adopted without a serious and time-consuming struggle which overcame active opposition to the amendment.

If the condemning authority is unable to procure title and possession of the land prior to the long delays inherent in court condemnation actions, this can have serious economic implications, since no access can be had for construction purposes.

Michigan, like most, if not all, other states, has a condemnation law which permits a property owner to contest the necessity of the project as well as the issue of the necessity of his parcel for the project. If he contests either issue of necessity, the municipality is not materially helped by the "quick-take" provisions of the law. The property owner must be accorded these rights for constitutional reasons. Thus, an assessment must be made as to whether there will be an undue number of contests on the issue of necessity and whether the timing and priority site area are critical in the ultimate site selection process.

Fortunately for the Muskegon project, we only encountered one contest as to necessity out of the 415 parcels to be acquired, so that was not a serious problem. That issue was later confined to the oil, gas, and mineral rights, and that was then easily resolved. We will report on our land acquisition later in this paper.

Another area of legislative authorization should also be explored in considering the problems of land acquisition. The ability of the municipality to comply with the Federal Uniform Land Acquisition and Relocation Act of 1970, is very important in the acquisition process.

This statute had only recently been adopted by the U.S. Congress and became effective on January 1 of 1971, just as the County was about to begin its land acquisition. Since the Muskegon project was federally funded, compliance with the law was deemed essential. Although the County did not have to comply with all of the provisions of that Act until July 1, 1972, if it could obtain the legal authority to do so before that date, its costs of relocation were 100 percent funded by the federal government. Thus, a strong incentive was presented to the various states to adopt such legislation to extend relocation benefits to the displaced persons, farms, and businesses.

The County recognized that the extensive benefits which could be accorded to the persons, farms, and businesses which were to be displaced would be of benefit in obtaining the necessary property. These "additive payments" substantially assisted the County in acquiring the lands, since these payments were in addition to the compensation for the land and property taken. The relocation procedures and benefits are described later in this treatise.

We can make this unequivocal statement. Without the ability to make these additive payments, the County would not have been able to obtain the necessary properties in the short time allotted to such acquisition.

The average family received an average additional $4,500, plus moving expenses of $300, in addition to being paid the fair price of the land. This "additive payment", thus, enabled the displaced person to purchase a decent, safe, and sanitary comparable dwelling.

Other legal, political, and practical considerations which are involved in land disposal include the ultimate disposition of cleared material, such as timber, brush, stumps, logs, and general debris. The cost of disposing of such materials can be substantial. With today's heavy interest in ecology, some resistance may be expected if burning is to be used for disposing of the combustibles for reasons of economy.

In the instant project, we encountered resistance from some environmental groups, as well as our own County Health Department on the open burning of the unsalvagable trees and stumps. We were, however, able to resolve these problems by negotiating acceptable guidelines to govern such burning.

Post-Site Selection Planning

After the site has been selected and the public relations program is in the process of development and refinement, the municipality must adopt and establish its policies and procedures pertaining to the actual land acquisition. An acquisition plan should be developed early in the proceedings, well in advance of the actual site selection. Thus, experienced legal counsel should be selected to assist in developing the plan and advising the body as to all applicable laws, rules, and regulations. The assistance of a real estate broker who is knowledgable and experienced in large land acquisitions is essential.

While a plan of procedure can be devised by the broker and attorney, the plan must be presented to the legislative or administrative body for review, revision, and approval. Such a review involves a myriad of policy and practical decisions which must be made:

1. Selection of a competent land acquisition co-ordinator who can establish a land-classifications system, acquisition map, and generally coordinate the activities. A progress chart must be developed to keep track of each parcel.
2. Determine whether title insurance should be utilized, rather than obtaining abstracts of title with attorney's title opinions. Select the title company or attorneys. (In Muskegon, we used the insurance system, since it was more expeditious and inexpensive.)
3. Obtain Title Searches for the reasons hereinbefore cited.
4. Select appraisers and the manner of such selection.

Since a large number of parcels may be involved, it is well to consider the retention of an appraiser with a staff sufficient to perform the task within the time limits.

More than one appraiser may be needed for the lands, especially if the parcel has substantial value.

Specialized appraisers or experts may be needed to appraise timer, Christmas trees, oil, gas, and mineral deposits, etc.

Problems are encountered in permitting an appraiser access to the site. The federal law requires the condemnor to permit the property owner to accompany the appraiser when he examines the property. This is a very cumbersome, costly, and impractical requirement, since the property owner often is hard to contact, breaks appointments, and the like. They often cause the appraiser to spend unnecessary time to listen to many irrelevant facts and circumstances.

Some persons deny access under any circumstances, so this presents problems as to appraisals which need to be resolved. Public relations is essential here. Absentee ownership is also a problem. So are loose dogs who are unfriendly to strangers.

5. Determine whether the land will be acquired by employees of the municipality or by an outside firm.

How are they to be selected - qualifications, etc.

If an outside firm, is selection by bid or negotiation.

6. Determine the method of compensation for land acquisition agents.

Muskegon County elected to use outside firms to handle the acquisition, and we would do so again. All interested real estate brokers were invited to submit bids and specifications were drawn.)

The County also agreed to pay a substantial bonus if 75 percent of the parcels were acquired within seven months. This incentive was very helpful in speeding the acquisition. A report on this will follow.

7. Establish an acquisition schedule and priority parcels. This is essential to meet construction schedules.

8. Determine how relocation is to be handled, i.e., in-house or by an outside firm. Select the method.

Our County also used an outside firm to perform this task, rather than attempting to train and supervise its own employees. There are many reasons to prefer an outside firm because of County labor contracts. We would use an outside consultant again, if the need arises.

9. Select one or more attorneys to handle the condemnation trial work. Here is an opportunity to retain the best and most experienced counsel in the area before they are hired by the property owners.

10. Determine how the real estate closings will be handled. We recommend the use of a title insurance company and the same one as issued the preliminary title commitments. The property owners will trust the company to handle the deal as an impartial agent.

It also helps the municipality, since the title company is then responsible for seeing that all instruments are recorded to comply with the conditions outlined in the preliminary title commitment. We had them make the computations of the prorata taxes, etc. and the County thus issued just one check. The title company made all of the disbursements to pay back taxes, assessments, mortgages, and the like.

Acquisition Plan

After the above ten major determinations have been made, the municipality must establish the procedures and policies for acquisitions.

Muskegon County used the following basic plan:

1. Appraisals were ordered.
2. Appraisals were reviewed by the Board of Public Works after preliminary review by the director, general acquisition attorney, and the acquisition broker.
3. Appraisal amount was then either approved or sent back for review by the Board.
4. After Board approval, a purchase agreement was signed by the County and delivered to the broker.
5. This purchase agreement was then presented to the property owner by the broker, together with a copy of the appraisal report. (This complied with the Federal requirement on acquisition.)
6. The broker then attempted to explain the proposal and appraisal.
7. If the price was not acceptable, the broker received the criticisms and relayed them back to the appraiser, if he thought they had merit.
8. The broker then negotiated a price, if possible. If the demanded price was within reason, the broker had the owners sign an option which could be presented to the D.P.W. Board.
9. If the deal was accepted by both sides, the matter would be turned over to the title company to close the deal.
10. If a mutually acceptable deal was not made, the Board would adopt a resolution authorizing condemnation proceedings to be instituted.

The preceding ten items are only a brief outline of the basic land acquisition procedure and should not be construed as an exclusive list or the only policies and procedures involved.

Relocation

At the same time as the land acquisition procedures are in process, a plan as to relocation has to be developed, since acquisition and relocation are directly related to one another.

It is well, however, to select a different firm to handle relocation than the acquisition broker's firm. While the two sums are considered together, it is far better to have each initially considered on its own peculiar criteria.

After the firm is selected, the following general plan and procedures were followed:

1. An immediate survey and census of the potential displaced persons must be conducted.

This is critical, since once a project is under way and the extensive benefits become known, the number of families appears to increase by magic. In Muskegon, we thought we had 160 families involved, and one way or another, it increased to 200. We found there were all sorts of oral life leases (legal in Michigan) which required us to relocate tenants and roomers.

2. A series of public meetings to explain the benefits should occur *after* the thorough census is made for obvious reasons.

3. The relocation agency then begins gathering the necessary information and attempts to locate comparable housing which will fill the needs of the relocatee and qualify as decent, safe, and sanitary.

We insisted on having the building inspector examine every house into which a family intended to relocate. This helped establish that the place met codes and was decent, safe, and sanitary under the regulations finally promulgated by the EPA. We paid the fee for this inspection, as well as for a termite inspection. These proved to be very wise, since we ran into several problems.

4. After the comparable dwelling was selected, the amount of the proposed additive payment was determined and presented to the Board of Public Works for review.

5. If the Board approved, the displaced persons were informed of the action. If not, it was sent back for further review.

6. If the relocatee was not satisfied, an appeal procedure was established, so the appellant could be heard.

(Note: Items 4, 5, and 6 are extremely time-consuming, since there are many issues to resolve. It takes a Board which is willing to devote many long hours to careful review, in order to be fair to the property owner, as well as the general taxpayers.)

7. After final determination, the relocatee would be paid his additive payments which were required to be invested in the actual new dwelling.

Care had to be taken, in order to ensure that no frauds were perpetrated on the County and EPA.

There are a myriad of problems in administering such a program. Another whole paper could be devoted to that subject.

8. The moving expenses are also determined and allowed on a schedule. rather than actual estimates. If a relocatee wishes, however, he can have his actual costs paid, but they rarely exceed the allowable estimates, so the relocatee moves himself and pockets the money.

9. A time is also established for the actual move and to vacate the premises. This must be closely coordinated with the priority schedule for land, the availability of the new housing, etc.

10. As an absolute last resort, forcible eviction may be necessary. We were fortunate, however, in that we were not forced to evict anyone. Only one action was commenced, and that was occasioned because the tenants were in a divorce action which complicated matters for us. They both left without any fuss after the Court entered a judgment in favor of the County. A neighboring community was not so fortunate, since they had to bodily carry out some elderly owners, all of which did not present a good public image.

As stated earlier, acquistion and relocation must go hand-in-hand in order to obtain title and possession of the lands expeditiously.

Water Sampling

The County deemed it both prudent and desirable to conduct thorough tests of the water quality of the private wells located within one-half mile of the outer perimeter of the site. These were conducted well in advance of commencing the operation of the System, so if a problem later developes with respect to their well-water, the County will have the samples for base data and comparison purposes.

The State of Michigan Department of Natural Resources and the State Health Department were also concerned that the present groundwater table under and surrounding the site will not become contaminated by admission of any of the effluent. In order to provide information on the present quality of the groundwater supplies in the area, the sampling and analysis program was carried out by obtaining samples of all the working wells in the areas immediately adjacent to the land disposal area. This monitoring program also provides the necessary data to prove that no contaminants are leaving the site through mixing into the groundwater table.

Miscellaneous Problems

In setting up the specifications for land clearing, it was decided to give all acquired buildings to the contractor for demolition. During the development of the relocation plan it was determined by the Department of Public Works Board that a few (about 25) of the dwelling units were of sufficient quality to permit the former owners to buy back for remodeling and moving to another site. If the former owner did not desire to move and remodel these homes, they were advertised and bids taken from the general public for their salvage or removal.

One problem that became apparent from almost the first acquisition, was that of vandalism and pilfering. It seemed that as soon as a party moved, the area "jungle telegraph" would alert those in the habit of making "moonlight requisitions" to become active. Every effort by the county sheriff and other local authority proved of little or no value. This vandalism and thievery continued throughout the acquisition and relocation phases.

Another relocation problem was what to do with the party who could not obtain financing at a reasonable rate to provide for the relocatee to move into decent, safe, sanitary housing. In this area, the County Board decided to act as the mortgagor and provide these people with direct financing, as provided for in the Uniform Relocation Act. Fortunately, we were only faced with three cases of this type.

Two complaints were filed against the County under the State Civil Rights Law. We were charged with discrimination because of race, color, and national origin by one black lady and a Mexican family. These complaints were withdrawn or dismissed after investigation proved them to be without merit.

We feel the complaints were filed to put pressure on the County to give the complainants more favorable treatment.

Many other problems were encountered which are too numerous to mention here, but they were relatively minor and were resolved without the necessity for planning in anticipation of the problem.

Public Relations

All through this paper reference is made to adequate planning, not only for the technical phases of the project, but for all important land acquisition and relocation phases as well.

In the initial budgeting there must be sufficient funds established to provide for informing the local political structures and those people directly involved in the proposed land disposal area of the project in all its phases from the very inception of the plan.

In looking back on the Muskegon project, with the advantage of 20-20 hindsight, we can see where a public relations firm or consultant should have been in on the ground floor to deal with the problem of getting the information on the entire project before the people, industry, and the politicians involved.

The public relations team should have a hand in the early planning of the land acquisition and relocation policies and procedures. They should also have the responsibility for the conduct of public informational meetings to be held throughout the project area, as well as the more common use of the media.

In addition to the regular public relation channels, there must be support gained from the State levels, such as the Legislators and Health Department officials. In Muskegon, a task group of community and industrial leaders proved to be invaluable in this area, as well as gaining community support, but would have been of greater value had they had the professional guidance of public relations expertise early in the project planning, especially in working with well-meaning environmental groups.

The question of removing public land from the tax roles was well-handled in the Muskegon project. It was a policy adopted in the early stages that a payment in lieu of taxes, based on a base-year valuation, would be made to the governmental unit within whose jurisdiction such land became county property. This payment would then continue to be borne by the system as an annual operation cost. This was of substantial help in overcoming the opposition of the townships and school districts of a substantial portion of their property tax base.

Experiences in Execution of the Acquisition and Relocation Plans

Acquisition

Some of the experiences in the Muskegon project may be helpful in relieving the apprehensions which have been raised in our earlier discussions of the problems we encountered.

The County Board of Public Works engaged a private real estate firm to perform the acquisition task. Their contract provided for a base fee of $80,000 and a $20,000 bonus if at least 75 percent of the parcels were acquired in a seven-month period. The firm had a substantial staff and was able to qualify for the bonus.

The firm was authorized to begin making contacts with the property owners on September 1, 1971, and had acquired 85 percent of the parcels by May 1, 1972, just eight months later. They gave special attention to the priority parcels as directed by the County pursuant to the engineer's and contractor's schedules.

Only 38 parcels could not be acquired through the negotiation process, and thus, had to be assigned for condemnation. Several parcels had one owner, so only sixteen suits were filed and several of those settled before trial. As of July 1, 1973, only eight suits are pending trial.

The County used the quick-take provisions on the 38 parcels, so it was able to obtain title and possession of the lands in sufficient time so construction was not delayed.

The County was able to acquire complete control of all necessary properties within one year of the time the parcels were assigned to the real estate brokers for acquisition.

The appraiser, of course, was engaged early in the proceedings and made a preliminary appraisal of the probable land costs prior to the sale of bonds and receipt of construction bids. This should have been done, however, in the site selection phase of the project.

The land costs, including administration, totaled $5,000,000 or $500 per acre. The legal and administrative costs were quite low, less than $400,000. These included the appraisal fees, land acquisition real estate agents' fees, title insurance, legal fees, closing costs, and other administrative costs.

The actual land costs were somewhat higher than the preliminary appraisal figure, but were considered reasonable.

The County was very well-satisfied with the performance of its real estate acquisition firm and the other aspects of acquisition. The board was especially pleased with its ability to acquire nearly all of the parcels (92 percent without legal action). Over 80 percent of the parcels were acquired within five percent of the appraisal amount established by its appraiser. As we previously pointed out, the relocation benefits had a substantial effect upon this accomplishment.

Acquisition must also be very closely administered and coordinated with construction schedules for the project.

We were also fortunate in that there was only one contest as to necessity.

While there were substantial doubts as to the project harbored by the residents in and around the site area, some of the unrest was settled by a suit the County instituted for a Declaratory Judgment against the opponents of the project. The trial of this case and the unanimous favorable decision of a three-judge panel of circuit judges had a quieting influence on the whole community. The decision also discouraged the property owners from attempting to contest the issue as to necessity, and thus, made the quick-take remedies meaningful.

Relocation

We have previously cited the great and helpful effect of the Federal Uniform Land Acquisition and Relocation Act of 1970 upon the land acquisition phase of the project.

Approximately 200 families were displaced, including four farms and also one business. The benefits paid out to the displaced persons totaled about $1,000,000, and the cost of administration for the relocation program totaled about $300,000.

The average per family additive benefit was $4,500 and a dislocation allowance of $200 and about $300 in moving expenses, for a total of about $5,000 per family on an average. A few persons received the maximum of $15,000 for additive payments while others received very small payments in addition to the land values.

If the Muskegon experience is at all typical, any land-use system which requires the relocation of property owners from the proposed site will meet with resistance from many of those persons who are to be moved. This is a definite social problem that must be considered in planning. Furthermore, whenever a substantial number of voters are unhappy, political repercussions, at least at the local level, are bound to occur. The Muskegon project necessitated the relocation of approximately 200 families to make available the 10,000 acres for the project site. Almost from the inception of public disclosure as to the location of the project, hostility from the residents of the area displayed itself in several ways.

Almost immediately, signs went up around the area designating the site as "Sewer City". And, of course, the local paper ran a lively column in, "As The Public Sees It".

In spite of the heat generated, however, most politicians at all levels responsible to the constituency were in favor of the program and actively supported it. Without this support, the project would never have gotten off the ground. It should be remembered, however, that there will be those politicians sitting in the weeds hoping to make political hay if the project fails. These politicians, in the Muskegon experience, were too few in number to scuttle the project. However, they provided a ready ear to disgruntled relocatees, if not active encouragement. Therefore, it must be apparent that before serious consideration of a land-use system, great effort must be expended to inform and educate politicians, hopefully to obtain their active support.

Of course, the people to be relocated cannot be ignored. They must be fairly treated in every respect, even when they are unreasonable in demands. Hardly anyone is happy to see the government step in and remove them from their property, especially if it has been theirs for many years.

The Muskegon project site is located in what was a rural, sparsely populated, farming area. In setting up the relocation phase of our project, we ran into a wall of distrust. We even encountered the situation where persons from outside the project area, in fact from another county, would attend public meetings and openly accuse us of being "Communist land-grabbers" intending to use the project to line our own pockets. Hand-in-hand with their distrust was the fear of unfair economic advantage.

In this latter respect, shines one bright light. In January of 1971, the new Federal Relocation Law went into effect. This law provided certain financial assistance to those relocated as a result of a program wherein any Federal funds are involved. In proportion to the federal government's share of project costs, the federal government supplied matching funds, along with local funds to provide relocation benefits to those to be moved.

Basically, the benefits include moving expenses and also what are termed "differential payments". Differential payments are payments to make up the difference between the amount paid for a person's home and the amount necessary to purchase that person a comparable, decent, safe, and sanitary replacement home. There are other benefits available to tenants, businesses, and farm operations.

Although this law will increase, substantially in some cases, total project costs; many human problems are more adequately cared for. One of the great injustices of the use of the condemnation power has been in economics, wherein those forced from their property can find replacement housing only at a price higher than received for their own property from the condemning authority. And, furthermore, in many instances the situation arose where those forced to move simply replaced themselves in ghetto type housing unfit for human habitation.

Muskegon was the first major EPA sponsored project to be affected by this law. We found that because people could look to the relocation benefits to fill out the economic package offered, very few cases went to the courts for condemnation.

However, this can be a two-edged sword. In some instances we found that employees of the agency responsible for buying the land were promising greater benefits than could be supplied under the relocation law. Of course, this led in some instances to cries of betrayal and unfair dealing.

The problem of alleged broken promises reared its hoary head in several situations. We found that certain of the relocation agents themselves either promised too much or what they did say was misconstrued by the individual relocatee. Many times relocatees would attend appeal sessions before the Board of Public Works to argue "But this isn't what Mr. ------ promised." Or "Mrs ------ said that I would receive $X dollars, instead of the amount awarded by the board."

These communication problems were probably the largest problem we had after it was clear in the people's minds that indeed the project was going to be a reality.

Therefore, along with education of local politicians, extensive efforts should be made to inform the people of both the purpose and effect of the project itself and also the benefits to be made available to them.

We held public meetings, passed out pamphlets, and prepared newspaper explanations. But all of these efforts will be unavailing if your own people are not qualified or are improperly trained for the job.

The staff personnel must deal with the people to be relocated on a daily basis. This means that if they are properly trained as to the benefits available, and if they are chosen for their ability to deal with people, many of the problems earlier discussed may be eased.

Of course, each project will face its own peculiar problems. The Muskegon project involved an innovative system that went through a court test. Therefore, many people resisted, feeling that the project would fail. Furthermore, Muskegon was the first major test of the newly-enacted relocation law. We decided to utilize it, yet in several areas we did not know how to apply it, since no guidelines had been promulgated by EPA due to the recent passage of the Act. This led to misunderstandings on the part of staff people which was all too often passed on to the people in the project area. And, of course, few projects will be as large as the Muskegon project.

Many problems, however, will be similar, requiring for planning purposes the suggestions we have outlined above.

In summary, the ability of the County to extend these benefits made the acquisition far easier and much more equitable to the displaced persons.

CONCLUSION

Although many problems are encountered in acquiring large land areas for the recycling of sewage effluent for large metropolitan areas, they can be resolved by careful planning and attention to public relations.

We have outlined in this paper the need for close cooperation between engineering and planning with the persons who will be responsible for the land acquisition phase of the project.

A competent public relations firm should be retained as soon as possible, so proper community support can be supplied during the project. Most of the opposition stems from lack of information and ignorance rather than fundamental objections.

Competent and experienced technicians are, of course, essential in the legal, appraisal, acquisition, and relocation areas.

The Muskegon project will be very closely monitored and scrutinized during its operations, and we feel that many of the fears and concerns of the public will be reduced or eliminated by our experiences. The EPA research and development grants have provided the necessary funds for this demonstration.

We predict that after the Muskegon project proves successful, there may be no need or requirement for the municipality to own all of the lands used for land disposal and no need to displace a large number of families. We are confident that after the technological data has all been gathered and evaluated by the industry the effluent will be disposed on leased lands and farms. It may even be sold to farmers for fertilization purposes.

We also wish to emphasize that the capital costs, operating costs, and problems in establishing a system of recycling effluent should be compared with the same costs attributable to the conventional advanced treatment systems. Obviously, the comparative effectiveness of treatment is of primary importance in the consideration of treatment alternatives.

We also wish to point out that although a large land area may be needed or required in land disposal, planners must consider that the lands may be reclaimed and the effluent utilized as fertilizer. In addition, the disposal area may be utilized for multiple uses. A portion can be used for solid waste disposal, electrical generating facilities, recreation, wildlife sanctuaries, and many other opportunities which have not yet emerged.

We conclude with a quotation from the federal Environmental Protection Agency's 1971 Report on *The Cost of Clean Water* (Volume II):

"The (land treatment procedures) have the great virtue of recycling the materials so disposed, both by replenishing water tables and by converting and utilizing organic and inorganic waste matter in natural life processes of decay and growth. Their secondary merit is more germane to this discussion. Water reaching watercourses after passage through the filtering and decomposition processes afforded by soil is far purer—provided that soil loading rates are not exceeded—than any waste treatment process short of distillation could make them."

DISCUSSION

QUESTION: J. Menzies, United States Department of Agriculture. I would like to direct a question to Mr. Postlewait concerning the remark he made about the health authorities changing their mind on whether the landowners would stay or not. I would like to ask him the general question about what they found out in Muskegon about the relationship between Federal, State and local health authorities, and did they ever get the lines of authority clearly figured out?

ANSWER: I think that would be a good topic for another paper. I don't know whether the State and the Federal people have gotten together under what extent myself. We have had several meetings in certain areas that require exploration such as virology and so forth, and I don't know just what the inner relationship between the State and Federal are in some of those areas.

QUESTION: J. Menzies, USDA. How about the county?

ANSWER: The County Board of Health is governed by a board of county commissioners. The Department of Public Works is governed by a board of the county commissioners. Four of my seven board members are on the County Health Board.

QUESTION: Belford L. Seabrook, EPA. Mister Chairman (Darwin Wright, EPA), I would like to ask you a question. The Office of Research and Monitoring has a proposal from me for a research project. Perhaps you could tell us something about the status of that particular research project. Doctor Menzies is aware of that.

DARWIN WRIGHT: Which one specifically are you talking about?

QUESTION: Belford L. Seabrook, EPA. The one that I proposed, the health effects of sewerages and sludges.

ANSWER: Darwin Wright, EPA. We (EPA) have not in the past placed a large emphasis from a funding viewpoint on the health aspects of municipal wastewater treatment. We have recognized this problem and we are beginning in FY74 to work very closely with the health effects and health research people in EPA. We haven't defined all the activities we are going to do in EPA during this next fiscal year and in the following years, but I can assure you Belford, that the health aspects are becoming more important, both in terms of sludges and liquid effluents.

QUESTION: Parker Pratt, University of California. I would like to ask Mr. Postlewait if he would elaborate on the objections of the Environmental Protection Organization to his project. Give some of the details of their objections.

ANSWER: Most of their objections, sir, were in connection with the land itself. Now these weren't really the people that lived on the land that we were taking, the ones to be relocated. It seemed to be the people in the immediate vicinity.

The land is an unproductive, sandy soil that had been forested one time and then it turned into scrub, very low yields agriculture. One of the statements that was attributed to the county administrator was that a jack rabbit couldn't go across without packing a lunch. But there was a very high water table, within a foot or a foot and a half of the ground surface on a good amount of the area, and the argument these people had, was that we would be contaminating the water table and the wells in the area. This was their main concern. After we got into the land acquisition phase the active purchase of the land, and they learned of the money that was associated with the relocation program, a lot of these concerns seemed to vanish in almost a direct proportion to the amount of money that was paid for the land.

QUESTION: George Ward, Consulting Engineer, Portland, Oregon. Would you elaborate more on your nuclear plant considerations?

ANSWER: Rather than me fielding that question, I am going to turn that one over to Dr. Bauer.

ANSWER: William Bauer, Bauer Engineers, Chicago. Some of the main considerations were that the site afforded isolation for the power plant. The distance between the power plant site and the nearest house was roughly two miles, so that there was considerable isolation around it. And the second consideration was that there was a water supply available for make-up water for cooling. I think a third consideration that was important was that there was a main transmission line running right across the property that connected the pump storage plant at Ludington with Detroit and so if there were a power plant sited at this location, it would be a very short connection to the main transmission line.

Another consideration was the 1,700 acre cooling surface that would be available if they subsequently choose to use it. So far the negotiations provide that they have free choice of this and they don't have to use it. They might elect to use cooling towers instead, and I think one of the reasons is that they are waiting to see what the quality of the wastewater, treated wastewater, in the lagoons is, before they make up their minds on that. I have no doubt in my mind that it is perfectly suitable water, because a much poorer quality water is used almost every day in Chicago for condensor cooling by taking the water out of the ship canal, which many times during the year it is just plain raw sewerage because of the overflows from the combined sewers, and at all other times it is effluent that is probably not quite as good as the one that will be in the ponds at Muskegon.

The site also provided good foundations for a power plant. It was drilled in order to see that there would be no differential settlement problems. I think it is a good site all the way around, and it wasn't just fact that the isolation was provided, but it is a strategic location from the point of view of the power company.

QUESTION: Robert Schneider, Office of Water Resources Research, Washington, D. C. I have a question to direct to Mr. Bauer in view of the fact he seems to be answering some of the technical questions. Could you describe something about the monitoring program for or on groundwater in the area?

ANSWER: William Bauer, Bauer Engineers. The main thrust in meeting the objection opposing pollution of groundwater, was to control the direction of groundwater movement. This was one of the reasons why the groundwater table being close to the surface was actually an advantage by putting in an artificial drainage system, one could depress the natural groundwater level within the irrigation site and therefore make it a sink, so that the movement from the surrounding area was towards the irrigation site and not away from it. And, in a part of the site the drainage was done by wells because the natural water table is deeper than can be economically reached with pipe drainage and associated with all of this drainage system are perimeter observation wells in pairs so that one can determine that the direction of the groundwater movement to make sure that it is always in to the site and never away from the site, and the agreement with the health authorities is that the wells will be pumped to the extent necessary to maintain the proper gradient. This means that they will be pumped a varying amount depending upon the weather. During wet years the groundwater table will naturally rise, during years it would fall, and so in order to balance the piezometric gradient properly, one would pump less during wet weather, because you would normally have lots of surcharge outside, and during dry weather one would have to pump more and depress the groundwater level further in order to maintain that inward gradient.

The monitoring is systematic sampling of these perimeter wells and they have been sampled for the past six months. We have not yet started to irrigate. The treatment system is such that it takes something like ten months to fill up the lagoons, so the major part of the irrigation will be next year, although there will be some this fall.

The Properties of Sludges

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and
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Environmental Protection Agency

Sludge is a liquid containing contaminants removed from wastewater by physical, biological, and chemical treatments. Although sludge contains solids, the problem of its disposal is not primarily a solid waste problem; it is rather the problem of disposing of the water that is in close association with waste solids. The major part of the cost of sludge treatment and disposal is directly related to the tons of water associated with each ton of solids. A typical digested sludge contains about 20 tons of water for each ton of solids. A thin, waste-activated sludge from biological treatment may contain well over 100 tons of water per ton of solids (Table 1). Dewatering and drying sludge are expensive operations that can cost as much as $50 per ton of dry solids produced.

TABLE 1
Water Content of Sludges

Treatment	*Percent Moisture*	*Tons of Water/Ton Sludge Solids*
Primary Sedimentation	95	19
Chem. Precipitation	93	13.3
Trickling Filters		
Humus - Low Rate	93	13.3
Humus - High Rate	97	32.4
Activated Sludge	98-99	~65.6
Well Digested Sludge		
Primary Treatment	85-90	~ 7.0
Activated Sludge	90-94	~11.5

The quantities of typical sludges as they are removed from clarifier tanks or thickeners are shown in Table 2. There are several types of sludge that may be produced at different stages of a conventional waste treatment system. Figure 1 shows a typical flow sheet for an activated sludge plant. A trickling filter plant would use essentially the same flow sheet, substituting a rock or plastic-filled "filter" for the aerator. The biological sludge sloughed off a trickling filter is frequently called humus in England. It is similar but not identical to the organic humus found in good soils.

Raw primary sludge consists of readily settleable organic matter and fine silt. It is highly putrescible and cannot be stored even for a few hours in warm weather without some type of stabilization to prevent odors from decomposition.

Waste-activated sludge (WAS) is the product of biological multiplication of microorganisms feeding on soluble and suspended organic matter in the presence of dissolved oxygen. A major part of the microbial sludge is returned to the aerator; but a fraction, representing net growth, is wasted. Waste-activated sludge is also putrescible. It may be treated separately; it may be combined with primary sludge for further treatment; or it may sometimes be discharged directly to the influent sewer to be collected with the primary sludge.

Most of the bacteria in waste-activated sludge are floc-forming Zooglea, which are related to Pseudomonads. Up to 90 percent of the Zoogleal mass is extracellular jelly secreted as bacterial capsules[8]. This

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TABLE 2
Typical Quantities of Sludge Produced In Wastewater Treatment Processes

Treatment	*Keefer (1940)*	*Fair & Imhoff (1965)*	*Babbitt (1953)*	*McCabe& Eckenfelder (1963)*
Plain Sedimentation	2,950	3,530	2,440	3,000
Tickling Filter Humus	745	530	750	700
Chem. Precipitation	5,120	5,100	5,250	5,100
Activated Sludge	19,400	14,600	18,700	19,400

(Given as gallons/ million gallons sewage treated)

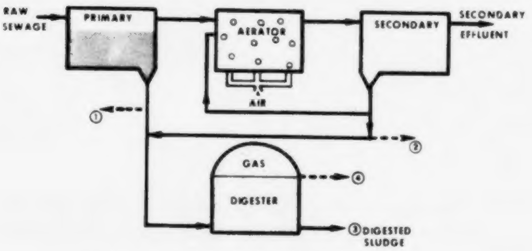

Figure 1: Biological Sewage Treatment.

gelatinous mass entraps small particles and organisms that settle with the bacteria, leaving a clarified final effluent.

Primary sludge, of course, contains high concentrations of fecal coliform bacteria, especially *Escherichia coli.* It also contains lesser quantities of intestinal and respiratory tract organisms, many of which may be disease-causing[15]. Cholera, typhoid, and dysentery are diseases commonly associated with fecal wastes[11]. Amoeboid cysts, intestinal worm eggs, and parasitic fungi may be transmitted by sludge[18]. Sewage treatment removes disease organisms from the effluent primarily by sedimentation; however, the organisms may remain in a viable state in the sludge[17].

The high bacterial content of raw sludge causes putrefaction within a few hours as oxygen is used up and anaerobic forms take over. Controlled putrefaction is called anaerobic digestion. If sludge is held for ten to thirty days in a digester, methane fermentation converts up to half of the organic matter to gases. A mixture of methane and carbon dioxide is produced that has about one half the heating value of natural gas and is contaminated with hydrogen sulfide and other odorous substances. There is enough energy in the gas to operate normal mechanical equipment and air compressors in a sewage treatment plant.

Organic matter in sewage includes food, paper wastes, and bacteria. The measure of organic matter is volatile solids, which are determined by loss of weight when the sludge is ashed under controlled conditions. The loss of solids as gases by digestion substantially reduces the quantity of sludge to be treated in subsequent operations. Well-digested sludge does not putrefy further; it is a black liquid resembling an emulsion of crude oil and frequently has a similar odor.

Digestion is usually carried out as a semi-continuous process[31]. A fraction of the digestor contents is withdrawn periodically, usually every day, and the volume is made up with raw sludge. The contents of the digester are mixed by gas evolution, usually supplemented by mechanical mixing or recirculation. If five percent of the contents of a digester is replaced each day, the nominal detention time will be twenty days (100 percent/ 5 percent per day); however, five percent of the sludge will have received only one day's exposure to anaerobic conditions. Digested sludge is frequently thickened by settling and the supernatant foul liquor is returned to the plant for further treatment. Characteristics of digester supernatant are shown in Table 3.

Anaerobic digestion is easily upset by a variety of toxic influents; therefore, aerobic digestion or aerobic stabilization of sludge is sometimes used, especially by small treatment plants. In this process, waste sludges are aerated as in secondary treatment until a large part of the volatile solids has been destroyed[19]. There is no generation of fuel gas and energy is required to provide aeration. The process is inherently more stable than anaerobic digestion and the final product is also free from further putrefaction.

Although conditions in digesters are unfavorable for the multiplication of most pathogenic organisms, they are not lethal, and the principal bactericidal effect appears to be related to a natural dieoff with time. Kenner *et. al.*[15], has reported bacterial concentrations in digested primary sludge and undigested waste-activated sludge. Table 4 shows representative

Table 3
Properties of Digester Supernatant (Municipal Wastewater Sludge)

Item	*Standard Rate*	*High Rate*
Total susp. solids (mg/ l)	4,000-5,000	10,000-14,000
Total solids (mg/ l)	2,000-3,000	4,000-6,000
BOD (mg/ l)	2,000-3,500	6,000-9,000
Volatile solids (mg/ l)	650-3,000	2,400-3,800
Alkalinity (MO)(mg/ l)	1,000-2,400	1,900-2,700
H_2S(mg/ l)	70-90	190-440
HN_3 -Nitrogen (mg/ l)	240-560	560-620
pH	7.0-7.6	6.4-7.2

After Maliva et al., 1971

TABLE 4
Bacteria In Sewage Sludge (per 100ml)

	Fecal coli ($x10^6$)	*Salmonella*	*Pseudomonas*
Raw Primary	11.4	460	46,000
Trickling Filter	11.5	93	110,000
Raw WAS - A	2.8	74	1,100
Raw WAS (Thickened) -B	20	9,300	2,000
Raw WAS - C	2.0	2,300	24,000
Anaerobic Digested Primary	0.39	29	34
Aerobic Digested WAS	0.66	150	100,000
Anaerobic Digested WAS	0.32	7.3	1,000
Iron Primary	32	460	21,000
Lime Primary pH 9.0	32	1,500	24,000
Lime Primary pH 11.5	0.014	< 3.0	< 3.0

After Kenner, 1972

data. The large differences between raw waste-activated sludges A and B, which were taken eleven days apart, are not unexpected and probably represent day-to-day fluctuations. Consistent differences between aerobic and anaerobic destruction of pathogens have not been reported.

Phosphates can be removed from sewage effluents by chemical precipitation. Chemicals may be added at any stage of treatment including treatment of the final effluent in a tertiary process. The added chemicals alter the physical properties of the sludges produced, sometimes favorably and sometimes quite unfavorably. They increase the mass of sludge produced and, of course, also increase its phosphate content. Chemicals that might influence agricultural properties of sludges include lime, alum, and iron salts. Lime treatment adds calcium carbonate and phosphate, and sometimes magnesium hydroxide to the sludge. Alum and iron salts add the respective aluminum and ferric phosphates and the hydroxides. All three hydroxides are bulky and hard to filter[1]. The same chemicals may also be added to sludge, after it has been separated from the effluent, to condition or stabilize it. Sludge is sometimes treated with large doses of chlorine that produce hydrochloric acid and chlorinated compounds and destroy ammonia and pathogens[12].

As an alternative to digestion, sludge may be stabilized by adding lime to a pH near 12[10]. About one quarter ton of lime is required per ton of sludge solids. Lime treatment provides a high level of bacterial disinfection (Table 5). Viruses are also destroyed by high pH although tuberculosis bacteria and some parasitic eggs may be more resistant. Work is underway to evaluate lime treatment of raw sludge for agricultural disposal. Since most soils and crops are benefited by lime treatment, there should be many agricultural uses for lime stabilized sludges. High pH inhibits bacterial growth but does not destroy organic matter. A lime sludge may putresce in a lagoon as bacterial action at the edges produces CO^2 and the pH drops. If a limed sludge is dispersed in a well-aerated soil, aerobic organisms will consume the organic matter and no putrescent odors should be produced.

Pasteurization is being used in Germany and Switzerland for digested sludge that is to be spread on pastures during the grazing season. Generally 25 to 30 minutes heating at 70° C is suggested for destruction of cysts, oocytes, pathogens, worm eggs, and viruses[12]. Direct steam injection is used since both organic fouling and inorganic scaling on indirect heat exchanger surfaces reduce the effective heat transfer. Recovery of heat from pasteurized sludge by means of vapor heat exchangers can be used, but it requires a substantial capital investment. Small plants cannot economically recover the heat of pasteurization. The sludge should be cooled enough to avoid killing vegetation before it is applied to the land.

Direct steam injection, which raises the temperature above 75° C for one hour, is an effective way to destroy pathogens and reduce coliform indicators below 1000 counts per 100 ml[7]. Table 6 indicates that

TABLE 5
Bacteriological Studies of Sludge Produced in Plant-Scale Tests of Lime Stabilization to pH 11.5

	Bacterial Count (organisms/liter of sludge)		
Sludge	*Salmonella Species*	*Pseudomonas aeruginosa*	*Total Aerobic Count* $\times 10^{-8}$
Alum-primary	110	1,300	41
Limed alum-primary	None detected	None detected	5.0
Ferric-primary	> 24,000	610	190
Limed ferric-primary	None detected	None detected	0.29

TABLE 6
Pasteurization Test Results

Organisms/100 ml

Test No. (1)	*Temp. 0° C*	*Time (hours)*	*Salmonella sp.*	*Pseudomonas aeruginosa*	*Total aerobic counts*	*Fecal coliform*	*Fecal streptococci*	*% Dilution after past.*
L-1	13.5(2)	-	7.3	20	2.5×10^6	6×10^5	16×10^4	
	59-64(3)	1	N.D.(4)	N.D.	2×10^6	9000	B.D.L.	18
		2	N.D.	N.D.	1×10^5	B.D.L.(5)	B.D.L.	
L-2	15	-	> 23	> 9.1	3.4×10^8	1.5×10^6	30×10^4	
	60-69	1	N.D.	N.D.	7×10^5	B.D.L.	B.D.L.	32
L-3	16	-	9.3	21	7×10^7	7.7×10^6	2.3×10^6	14
	63-66(6)	1	N.D.	20	6.3×10^6	6000	9×10^4	
L-4	15	-	23	150	2.5×10^8	2×10^6	5×10^6	
	67-75	1	N.D.	N.D.	6.4×10^6	B.D.L.	B.D.L.	22
		2	N.D.	N.D.	1.3×10^6	B.D.L.	B.D.L.	
L-5	36	-	29	> 1100	1.7×10^9	9.9×10^6	2.7×10^6	12
	68-73	1	N.D.	N.D.	$< 3 \times 10^6$	5000	5000	
L-6	18	-	3	7.3	1.2×10^8	1.9×10^6	6.5×10^4	52
	77-85	1	N.D.	N.D.	6×10^5	B.D.L.	B.D.L.	
L-7	14	-	240	43	1×10^8	1×10^6	6.5×10^4	59
	87-91	1	N.D.	N.D.	3×10^6	B.D.L.	B.D.L.	
Using Steam Gun								
	26	-	> 240	93	7.9×10^7	5×10^5	1.7×10^5	
P-1	38-55	1.5	> 240	N.D.	1.7×10^7	5×10^7	4.2×10^4	10
Through Copper Tube with 12 3/16-inch holes								
	25	-	> 240	16	1.8×10^8	8.4×10^6	2.1×10^5	
P-2	70-83	1	N.D.	N.D.	4.4×10^5	B.D.L.	B.D.L.	58
		1.5	N.D.	N.D.	4.5×10^5	B.D.L.	B.D.L.	
	59(7)	-	N.D.	N.D.	3.8×10^5	B.D.L.	B.D.L.	

Notes:

(1) L-number -- Laboratory Tests
P-numbers -- Large-Scale Tests

(2) Original Digested Sludge Temperature (typical)

(3) Pasteurization Temperatures (typical)

(4) N.D. -- None Detected (< 3/100 ml)

(5) Below detectable limits of analysis (< 1000/100 ml)

(6) Presence of *Pseudomonas aeruginosa* and relatively high fecal streptococci suggests that heat did not penetrate the sludge.

(7) After cooling with air to 59° C.

raising the temperature to 70° C for one hour will destroy pathogens, though coliform indicators may be above 1000 counts per 100 ml. Warm sludge can be applied to growing grasses if the temperature at the soil surface does not exceed 60° C. Because evaporative cooling of sprayed sludge can reduce the temperature significantly, and heat may be lost in transit, direct cooling may not be necessary in most cases. Adverse effects are not expected if hot sludge is applied to bare soil before crops are started.

The cost of pasteurization was calculated by Treibel in 1967 for German conditions. The heat for pasteurization was derived from the methane gas produced by the anaerobic digestion and heating costs were not included. The cost of fuel to heat sludge from 15° to 75° C was about $4 per ton of dry sludge. Total costs for pasteurizing will decrease as the size of the plant increases and can be expected to lie in the range $0.25 to $1.00 per ton of liquid sludge. On a solids' basis, a cost of $10 per ton is a fair preliminary estimate.

Heat treatment of sludge to improve dewaterability is carried out at temperatures above 160° C for about half an hour. These conditions will completely destroy all living organisms. If oxygen is present, some organic matter may be oxidized. The process is then called wet oxidation. All heat treatment processes increase the concentration of soluble organic matter and ammonia in the supernatant liquor or "soup." This soup, although sterile when it is produced, is a rich nutrient broth that can putrefy if it is allowed to come into contact with bacteria that are in the air or on container walls. The dewatered sludge is, however, resistant to putrefaction .

Lagoon or other storage for many months is frequently depended upon to reduce the numbers of pathogenic organisms, particularly those that cannot multiply outside the human body[13,17]. Storage may be necessary in any case if sludge is disposed of only part of the year, and additional storage lagoons can be built into the system to provide more protection against transmission of disease. Sludge will settle in lagoons to form a mud that may become too thick to pump. Resuspension of the thick mud in water or effluent may have to be done before the sludge can be removed from the lagoon.

Smaller plants traditionally dry digested sludge on sand beds. Drying is facilitated by drainage of much of the water through the sand to underdrains from which it is returned to the plant[2]. Storage time of the drying beds is usually several weeks to months and provides time for a significant dieoff of pathogens. Many small treatment plants make piles of dried sludge available to anyone who cares to haul it away for use in agriculture or gardening[5]. A few plants are able to sell dry sludge for its organic nitrogen content that is released slowly, making it desirable fertilizer for lawns and golf greens.

Waste-activated sludge is dried in heated dryers and sold by a few cities. Chicago used to sell for $15/ ton dried sludge that cost them $60 a ton to "manufacture"[6]. Milwaukee has developed a capable sales organization that markets dried sludge under the name "Milorganite"[33]. Some cities sell sludge to fertilizer manufacturers who incorporate it into specialty products and handle the marketing of the product[30]. Sale of dried sludge never makes a profit but it reduces the costs of disposal below the costs of other methods such as incineration. High temperature in the dryers destroys most of the bacteria, but the dried sludge may putrefy if it is allowed to get wet in thick layers on the ground.

Sludge contains the major plant nutrients nitrogen, phosphorus, and potassium at levels that are about one-fifth of those found in chemical fertilizers. Table 7 expresses average analyses as the elements and in terms of more familiar units. The low analyses account for some of the difficulties in marketing dried sludge as a fertilizer. To get comparable responses to nutrients, about five times as much sludge as chemical fertilizer must be shipped, stored, and spread on the fields. Distribution costs that are proportional to weight are a large part of the total costs of fertilizer, therefore, high analysis fertilizers have a substantial cost advantage for commercial farming. The sludge that is sold for agriculture and horticulture is bought for its content of organic slow-release nitrogen and other organic matter that improves the physical properties of the soil.

TABLE 7
Mineral Nutrients Percent of Dry Sludge Solids

Total N	3.5 - 6.4
Organic N	2.0 - 4.5
P	0.8 - 3.9
P_2O_5	1.8 - 8.7
K	0.2 - 0.7
K_2O	0.24 - 0.84

After Peterson, J.R., 1972.

When the purpose of sludge spreading is to dispose of sludge at the lowest cost, much higher rates of application will be used. The limiting factor in many locations then appears to be nitrogen. Excess nitrogen is converted to nitrates that percolate down and contaminate the groundwater[13]. Public Health Service (PHS) and World Health Organization (WHO) drinking water standards of 10 mg/ l of nitrate nitrogen are exceeded in many groundwater supplies where fertilizer has been improperly applied to the soil.

Excess phosphate is strongly bound to most soils and significant levels of soluble phosphates are virtually unknown in groundwater supplies. Potassium salts from fertilizers have not caused significant pollution of groundwater[13,23].

Sludge contains almost all of the metal ions that are discharged to sewers or extracted from plumbing. Heavy metals occurring in quantities that are significant to agriculture include zinc, copper, nickel, cadmium, mercury, and lead. Zinc and copper are essential micronutrients that are present in sludges at concentrations in excess of those present in soils. Analyses of sludges for metals show wide variations between locations reflecting local conditions. The statistical distribution of values tends to be log-normal with a few very high values that can ordinarily be traced to specific industrial discharges (Figure 2). Source control with limits on discharges of toxic substances is practiced by cities that use their sludge for agricultural purposes, but even the tightest source control is unlikely to reduce the metal content much below the median value. Table 8 lists the geometric mean values for metals in sludges based on a review of about 100 literature references and 80 additional samples recently collected from sewage treatment plants in this country[25]. The standard deviations of the logarithmic distribution are as great as 4- or 5-fold, so the numbers should not be used to predict permissible loadings in the absence of analyses on the sludges in question. Arithmetic averages are dominated by high values and are typically about twice the median value.

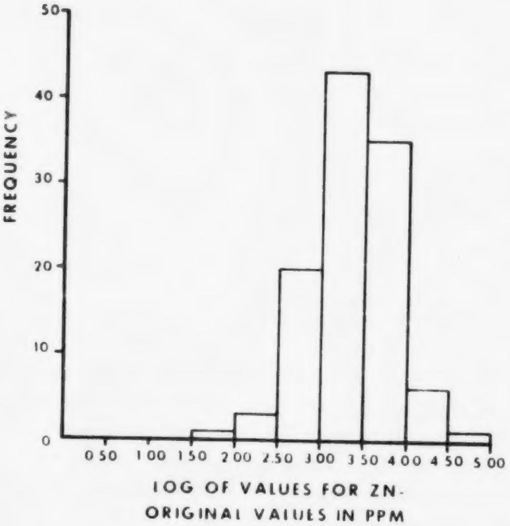

Figure 2: Distribution of Zinc in Sewage Sludge.

TABLE 8
Metals In Sludge
1971-1973

	Literature		*Atomic Absorption*
Element	*Geometric Mean (ppm)*	*Spread**	*Geometric Mean (ppm)*
Cd	61	5.89	93
Cu	906	2.66	1840
Hg	14.5	5.24	3.2
Ni	223	4.54	733
Pb	404	4.13	2400
Zn	2420	2.78	6380

* Spread is antilog of standard deviation of log-normal distribution.

The absolute quantity of metal added to the soil may have little relation to the concentration that is available to growing plants. Since organic matter in sludge complexes heavy metals, a typical response from adding sludge to a soil low in organic matter is to reduce the availability of metals, even though the sludge may contain more metals than the soil[28]. The availability of a metal in a soil depends on many factors including pH, organic matter, other metals, and the variety of the plant that is growing in the soil. Studies of highly metalized soils derived from mine dumps have shown that certain varieties of common plants have an inherent resistance to toxic metals that takes the form of a cytological barrier to absorption[27].

Lime inactivates most heavy metals by precipitation, making them less available to growing plants. Zinc toxicity from continued applications of sewage sludge in Nottingham, England, was easily corrected by treating the soil with agricultural lime[29]. Translocation of metals into plant tissue varies greatly with the element, plant species, pH, and other soil factors[26]. Much work remains to be done in the area of metal transport from sludge-treated soils to plants, but the long history of successful use of sludge as a soil amendment in agriculture indicates that the hazards are slight and probably are easily controlled by appropriate farm practices.

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DISCUSSION

QUESTION: John Walker, USDA, Beltsville. Just a quick comment and followed with a little question for Doctor Dean. On his liming sludge study, we were interested in liming sludges as they might be useful in agriculture and whether these high limed sludges would have an adverse effect on plant growth, and we are also interested in what would happen to the disease organisms with time after the sludges have been applied to soil. So we put some raw and digested sludges into the soil surface and rototilled it in, plus we put some in trenches in the soil and we studied the pH in the microorganism level and plant growth with time. We found after about a month the pH dropped. We asked Blue Plains to lime the sludges and then give them to use at pH's ranking from about eight to eleven and a half. The upshot of the whole thing was that in the beginning we had identical results to what Dr. Dean showed, but after they were mixed with the soil the pH levels dropped back down and instead of not finding Salmonella we then found Salmonella organisms even at the highest lime level, both in trenches and was mixed in the soil surface, so, my question is have you other work that would either tend to confirm or deny this type of finding, and would higher pH initially kill them once and for all?

ANSWER: We have a contract now with Batelle Northwest in Richland, Washington following the behavior of limed sludges. We don't have any results on the re-growth of Salmonella, which is what this appears to be. I don't know from the Beltsville experience whether the Salmonella that was re-growing was the same serological types or not. I suspect that the Salmonella types that re-grow in the soil might not be the same as those that are pathogenic. This is the sort of thing that we find very frequently that was referred to by the previous speaker. The natural coliform organisms in the soil, that have never been in a colon are distinguishable from the fecal coliforms. We don't have a full answer on that. We do know that a limed sludge if stored for too long will putrify.

QUESTION: John Walker, USDA. The microorganisms that came back were definitely fecal coliform organisms. I am not sure about the serology of the Salmonella. Do you know about that, Wiley?

ANSWER: Wiley Burge, USDA-ARS at Beltsville. We did not look at the pseudotype. We plan to do that.

QUESTION: Rufus L. Chaney, USDA. Mr. Seabrook mentioned earlier that there is a possibility that metal levels in sludges is going to fall drastically if ordinances promulgated under these current laws are used to diminish industrial releasing metals to the sewerage. I am wondering, have you predicted what levels we are going to have in sludges ten years from now. Let's say we have all these laws in effect by then and in progress. What are we are going to have then Dr. Dean and Mr. Seabrook and others?

ANSWER: Robert Dean, EPA. The reduction that we can expect is down not much lower than the load that we saw or the geometric mean. There is an interesting paper from New York on a symposium held last year on recycling of metals which is available from EPA. They found that copper, about a third of the copper in New York City's wastewater comes from domestic plumbing. Not copper pipes but brass fixtures rotting out. Likewise with the zinc. They made a very good job of knocking out and getting after the people who dump plating wastes, and you knock back quite away, but remember you yourself are excreting zinc. Now, we are not going to be able to go all the way back. We can get those that are up four times what a reasonable average is, but we aren't going to be able to get any substantial reduction in something as ubiquitous as copper or zinc. On the other hand I am very pleased to say that the battle against PCB is succeeding. As you know there was quite a flap about PCB's turning up and there is no carbon paper. They were being made by National Cash Register in Dayton, and their sludge was running around a hundred parts of PCB's when the national average is around three parts. So, a year and a half after the flap, we went back and they are way down and the other plants that were high, probably from recycled paper, are down into the normal level, so we are making progress. But I don't think you can do it on copper and zinc until you go to all plastic plumbing.

COMMENT: A. Kaplovsky, Rutgers University. As some of you gentlemen know, we are in a demonstration project which is funded by EPA and Ocean County, New Jersey. We made a study of various sludges in which we made certain there was absolutely no industrial waste whatsoever, and we did it on five separate digestive sludges and compared it with a whole series of analyses that I had gathered when I was Director of Research at the Chicago Metropolitan Sanitary District. Unfortunately I can only report that all metals that we examined, all heavy metals, came out in the same order of magnitude in domestic waste as the industrial waste that we found in Chicago, concentrations were unusually high and we are convinced that this is what we have now as background. The zinc levels, the copper, the lead, the cadmium and so on. The lead is what surprised us very much. Someone suggested that perhaps unleaded gasoline and it gets slushed into the sewers as storm water and it gets into some of the sewerage plants, but the lead levels were at the same order of magnitude. So, I don't think we have much hope unless you have a gross industrial waste product.

I might also add that my experience in Chicago was that they had a predominance of the metal plating industry located in the Chicago metropolitan area, so you are looking at a very high level compared to a municipal system.

QUESTION: Darwin Wright, EPA. I would like to ask Bill Rosenkranz to discuss something which the crowd here may not be quite aware, and that is the problem of heavy metals in urban run-off.

ANSWER: Bill Rosenkranz, EPA. I don't have any numbers with me, but we have recently published a report on urban storm waters that was done by URS. The heavy metal problem is very distinctive there as well as it is in other wastewaters. Lead contents were very high and actually after the storm you can measure the amount of lead discharged in a large metropolitan drainage area in terms of tons. This very clearly indicates that in any community where you have storm waters entering your collection system through a combined sewer or other means, the possibility of having elevated levels of heavy metals in sewerage and in the resultant sludges and effluent are probably higher than they are in other communities. And we have some further work going on to further define this in the Washington area being done by Biospherics. While I haven't seen the data yet, there was a news release that came from the contractor the other day, which indicated some of the same things that I just mentioned. The heavy metals and some of the other wastewater constituents in storm waters is a very significant problem.

Characteristics of Municipal Effluents

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ABSTRACT

Physical, chemical, and biological characteristics of municipal wastewaters are presented and discussed with respect to land application. Both constituents of raw wastewater as well as effluents from four types of plants are included. These constituents are compared to those of acceptable irrigation waters and to the relative amounts of each that would normally by applied to the land. The objective of this comparison is to put irrigation with municipal effluents into perspective. On the basis of the data presented and the corresponding literature review, several areas of research are outlined.

INTRODUCTION

Before the effects of effluents on the land can be understood or evaluated, it is necessary to know the characteristics of the waters being applied. Hence, the objective of this paper is to summarize the characteristics of municipal wastewater and the effluents from various common treatment processes. Several wastewater constituents will then be compared quantitatively to those normally applied to farm lands by irrigation and the addition of commercial fertilizers. These comparisons are intended to put our knowledge of effluent characteristics into perspective, as related to land application. From these comparisons and a review of the subject matter, conclusions will be drawn regarding the areas when additional information and research is needed.

Data presented herein were collected from a variety of sources. In addition to a literature search and a review of office files, much of the data was collected during the performance of a "State-of-the-Art" study presently being completed by the author for the USEPA[12].

Constituents of Wastewaters

The constituents of raw sewage and the subsequent treatment plant effluents depend upon the character of the municipal water supply, the industrial mix of the community, the proportion of commercial to residential development, and the nature of the residential community. Consequently no specific conclusions can be drawn for a community by reference to generalized data. Only trends or generalities can be developed and discussed from such data. The wide variations that can be encountered from drainage areas having selected land development characteristics and yet having essentially the same water supply are illustrated in Table 1.

Municipal wastewater has been characterized as weak, medium, or strong depending on the concentrations of various constituents[10]. The range of values for normally listed constituents is given in Table 2.

The characteristics of raw sewage are important if screened and comminuted sewage is under consideration for treatment by the overland flow or grass filtration method. For most application approaches, some form of pretreatment is practiced, consisting of at least primary treatment and probably secondary

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TABLE 1
Comparison of Sewage Characteristics from Areas of Selected Types of Development

	Residential areas				*Industrial areas*		
Constituent	*MD*	*LD*	*LD*	*LD*	*(1)*	*(2)*	*Combined municipal*
Total solids, mg/l	344	474	701	499	542	712	880
Suspended solids, mg/l	120	117	283	56	199	81	101
Volatile solids, mg/l	88	81	182	37	125	63	79
Settleable solids, mg/l	3.9	2.3	10.9	0.1	4.6	0.1	0.8
BOD, mg/l	89	61	129	315	1,002	198	294
COD, mg/l	260	205	422	426	1,689	367	542
Oil and grease, mg/l	25	18	29	34	12	53	41
Coliforms, MPN x 10^6/100 ml	84	79	52	297	653	150	680

Note: MD = medium density; LD = low density.
Source: Reference (9).

TABLE 2
Untreated Municipal Wastewater Characteristics

	mg/l (except as noted)		
Constituent	*Strong*	*Medium*	*Weak*
Physical			
Total solids	1,200	700	350
Total suspended solids	350	200	100
Chemical			
Total dissolved solids	850	500	250
BOD	300	200	100
COD	1,000	500	250
Total nitrogen	85	40	20
Nitrate-nitrogen	0	0	0
Ammonia-nitrogen	50	25	12
Total phosphorus	20	10	6
Chlorides[a]	100	50	30
Alkalinity ($CaCo_3$)[a]	200	100	50

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[a] Values should be increased by amount in drinking water.
Source: Reference (10).

treatment. Effluent characteristics from several primary plants located in various communities in California are given in Table 3. Except for alkalinity and TDS values, the concentrations of various constituents do not seem to vary widely from plant to plant.

Secondary treatment has been loosely defined for many years as either trickling filters, activated sludge, or some type of pretreatment followed by oxidation ponds. In order to compare the effluents from each of these processes, data were collected from several facilities for each process. Effluent characteristics for trickling filter plants, activated sludge plants, and oxidation ponds, are given in Tables 4, 5, and 6, respectively. The plants listed in these tables are mainly located in Southern California and in many cases the drinking water supplies are relatively highly mineralized. As a consequence the TDS and other specific mineral concentrations in these wastewaters are high. Average values of the constituents listed in Tables 2 through 6 for the various types of plants are presented in Table 7. As expected, the only constituents listed that are substantially lowered by secondary treatment are BOD and total nitrogen.

TABLE 3
Municipal Effluent Characteristics from Primary Treatment Plants

mg/l (except as noted)

Constituent	*Arroyo Grande*[a]	*Santa Barbara*	*Ventura (seaside)*	*EBMUD, Sp. dist. No. 1*
Physical				
Total suspended solids	--	--	--	102
Chemical				
Specific conductivity, mhos/cm	2,300	2,850	--	--
Total dissolved solids	1,344	1,898	1440	935
pH, units	--	7.7	7.6	6.8
BOD	123	110	162	216
Total nitrogen	51	21	35	41.7
Nitrate-nitrogen	0	0	0	1.4
Ammonia-nitrogen	41	16	25	11.6
Total phosphorus	12	14	10	7.5
Chlorides	528	657	395	264
Sulfate	70	222	298	133
Alkalinity ($CaCo_3$)	1,040	735	--	131
Boron	0.60	0.95	1.0	--
Sodium	330	460	320	209
Potassium	13	24	18	33
Calcium	11.9	134	102	31
Magnesium	3.4	42	46	14
Sodium adsorption ratio	6.8	8.9	6.6	7.8
Biological				
Coliforms, MPN x 10^6/100 ml	--	--	--	6.1

---

[a] Effluent applied to the land.

Sources: Column 1-3 - Reference (6).
Column 4 - Reference (8).

TABLE 4
Municipal Effluent Characteristics from Trickling Filter Treatment Plants

Mg/l (except as noted)

Constituent	*Carpenteria San. Dist.*	*San Luis Obispo*[a]	*Ventura (east side)*	*Laguna Co. San. Dist.*
Chemical				
Specific conductivity, μmhos/cm	2,150	1,140	--	1,700
Total dissolved solids	1,350	780	1,500	1,034
pH, units	8.1	7.3	7.5	7.7
BOD	6	15	10	40
Total nitrogen	12.7	25.2	11.2	16.8
Nitrate-nitrogen	8.8	14.2	0.0	2.5
Ammonia-nitrogen	0.0	6.1	8.4	9.3
Total phosphorus	9.1	13.0	13.0	16.9
Chlorides	343	158	352	254
Sulfate	275	115	600	280
Alkalinity ($CaCO_3$)	640	305	--	528
Boron	0.55	0.3	1.5	0.6
Sodium	305	150	370	245
Potassium	13	13	17	15
Calcium	100	30	120	70
Magnesium	52	49	61	41
Sodium adsorption ratio	6.0	3.9	6.8	5.8

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[a] Effluent applied to the land.

Source: Reference (6)

TABLE 5
Municipal Effluent Characteristics from Activated Sludge Treatment Plant

mg/l (except as noted)

Constituent	*Abilene, Texas*	*Conejo Valley San. Dist., California*	*Oak View San. Dist., California*	*Pomona, California*
Chemical				
Total dissolved solids	750	1,080	1,235	605
pH, units	7.1	7.2	7.6	7.7
BOD	17	40	18	6
Total nitrogen	12	33.4	21.3	28.0
Nitrate-nitrogen	0	0.0	3.6	12.0
Ammonia-nitrogen	12	30.0	16.0	13.0
Total phosphorus	9.4	13.4	16.0	--
Chlorides	168	167	299	107
Sulfate	--	330	256	86
Alkalinity ($CaCO_3$)	196	--	--	--
Boron	--	0.8	--	0.7
Sodium	192	260	215	101
Potassium	36	17	15	13
Calcium	17	40	110	42
Magnesium	44	33	47	26
Sodium adsorption ratio	5.6	7.4	4.3	3.0

Note: Effluent from each plant applied to the land.

Sources: Column 1 - Reference (12).
Column 2 - Reference (6).

TABLE 6
Municipal Effluent Characteristics from Oxidation Pond Treatment

Constituent	*Montalvo M.I.D.*	*Newberry Park Academy*[a]	*Saticoy San. Dist.*[a]	*Bishop*[a]
Chemical				
Specific conductivity, μmhos/cm	--	1,460	--	340
Total dissolved solids	1,775	1,012	2,330	204
pH, units	7.6	8.3	8.1	7.0
BOD	65	71	74	--
Total nitrogen	22.5	15.3	40.2	15.0
Nitrate-nitrogen	0.0	2.7	0.3	0.0
Ammonia-nitrogen	18.0	9.5	0.8	7.4
Total phosphorus	9.4	4.2	7.8	5.5
Chlorides	239	146	151	19
Sulfate	560	110	762	10
Alkalinity ($CaCO_3$)	--	1,084	--	280
Boron	1.2	0.7	1.4	.33
Sodium	335	267	390	38
Potassium	15	13	21	7
Calcium	122	47	178	23
Magnesium	72	31	91	1
Sodium adsorption ratio	5.9	7.4	5.7	2.1

[a] Effluent applied to the land.
Source: Reference (6).

TABLE 7
Average Effluent Characteristics from Various Treatment Plants

mg/l (except as noted)

		Secondary		
Constituent	*Primary*	*Trickling filters*	*Activated sludge*	*Ponds*
Chemical				
Specific conductivity, μmhos/cm	--	1,663	--	--
Total dissolved solids	1,402	1,166	917	1,330
pH, units	--	--	--	--
BOD	152	17	20	70
Total nitrogen	37	16	23	23
Nitrate-nitrogen	0.3	6.3	3.9	0.7
Ammonia-nitrogen	23	5.9	17	8
Total phosphorus	11	13	12.9	6.7
Chlorides	461	276	185	138
Sulfate	180	317	224	360
Alkalinity ($CaCO_3$)	635	491	--	682
Boron	1.2	0.7	0.7	1.2
Sodium	329	267	192	257
Potassium	22	14	20	14
Calcium	96	80	52	92
Magnesium	34	50	37	48
Sodium adsorption ratio	7.5	5.6	5.0	5.2

Sources: Tables 3 through 6

A limited amount of information on heavy metals in the effluents described is available and is shown in Table 8. None of the concentrations shown would preclude the use of the effluent for irrigation of most crops. The National Technical Advisory Committee in their report on Water Quality Criteria lists trace element limits for irrigation[19]. Checking this list, it is found that the only element approaching toxic levels is copper at 0.1 mg/ l. Each heavy metal listed except iron, has a lower limit of tolerance for use in irrigation water. This limit has been defined, however, for only a few crops and a few soil types. Much more research is needed in this area.

It should be noted that although heavy metals are present in municipal effluents the amounts are generally quite small. For example, an activated sludge effluent with a zinc concentration of 0.06 mg/ l, irrigated at a rate of 8 ft/ yr would add only 1.3 lb/ acre to the soil in a year. For some plants, an additional fertilizing with zinc would be required for satisfactory growth. For example, where zinc deficiencies are found in plum and prune orchards, addition of from 10-15 lb/ acre of zinc is recommended.

Characteristics of Wastewaters

The characteristics of wastewaters may be classified as physical, chemical, and biological. Each of these categories are discussed in the following paragraphs.

Physical Characteristics

The most important physical characteristic of wastewater is its total solids content. The solids include floating, suspended, colloidal, and dissolved matter.

The solids are important because they have a tendency to clog the soil pores and coat the land surface. Other physical characteristics are temperature, color, and odor. Temperature is not a great problem because municipal wastewater effluent has a fairly even temperature, 50° F to 70° F, which is not harmful to soil or vegetation. It is beneficial in that in winter, it has a thawing effect on frozen ground and may keep soil bacteria alive. Effluent has been used to spray on crops in freezing weather to form an insulating ice coating which protects the crop from cold air[11].

Color of effluent has little effect on the application to the crops, but it can be used as an indicator of the composition of the wastewater. Fresh sewage is usually grey; septic or stale sewage is black. The presence of industrial wastes can give the sewage color from chemical in the waste.

Odors in wastewater are caused by the anaerobic decomposition of organic matter. Although hydrogen sulfide is the most important gas formed from the standpoint of odors, other volatile compounds such as indol, skatol, and mercaptons also cause noxious odors. These odors are then released to the atmosphere by spraying or aerating.

TABLE 8
Concentrations of Heavy Metals in Wastewater Effluents

Constituents μg/l (ppb)	*Primary*	*Type of plant*		
		Trickling Filters	*Activated sludge*	*Ponds*
Arsenic	2	3	8	6
Chromium	0	0	10	7
Copper	60	70	40	100
Lead	55	15	10	20
Manganese	35	10	10	30
Zinc	750	85	60	200
Iron	830	160	320	390

Note: Data taken from at least 2 plants.
Source: Reference (6).

Chemical Characteristics

The chemical properties of wastewater can be divided into three categories: organic matter, inorganic matter, and gases.

The organic matter in wastewater is in the dissolved form as well as settleable solid form, and it is principally composed of proteins (40 to 60 percent), carbohydrates (25 to 50 percent), and fats and oils (10 percent). Other organic compounds, such as phenols, surfactants, and agricultural pesticides, are generally present in small quantities. Only when the trace organics reach higher concentrations do they become a problem. Ordinarily these substances are in such a small quantity that they have no short term effect on the soil or vegetation; however, their effect on groundwater quality is a point of concern. Long term effects of trace organics have not been adequately determined.

Many of the inorganic compounds provide nutrients for the vegetation, but they also can be toxic to plants at certain concentrations. Examples include boron, lead, nickel, and zinc. The major plant nutrients present in wastewater are nitrogen, phosphorus, and potassium. The aggregate of dissolved compounds is the TDS (total dissolved solids). The TDS content, often measured as electrical conductivity, is generally more important than the concentration of a specific ion such as chloride. TDS values above 750 mg/l for irrigation waters will require leaching either by adding excess irrigation water or from rainfall.

The relationship between the principal cations in wastewater—calcium, magnesium, sodium, and potassium—is of importance. When the ratio of sodium to the other cations, especially calcium and magnesium, becomes too high, the sodium tends to replace the calcium and magnesium ions on clay particles. The predominance of sodium ions on clay particles has the effect of dispersing the soil particles and decreasing the soil permeability. In most cases permeability of soil becomes a hazard before sodium affects plant growth. In a few plants this is not strictly true, notably avocados. To determine the sodium hazard, the SAR (sodium adsorption ratio) was developed by the U.S. Department of Agriculture Salinity Laboratory and is described in detail in Agricultural Handbook No. 60[18]. It is defined as follows:

$$SAR = Na / [1/2\,(Ca + Mg)]^{1/2}$$

where Na, Ca, and Mg are concentrations of the respective ions in milliequivalents per liter of water.

Because the presence of bicarbonates and carbonates may result in precipitation of calcium carbonates and thereby release more exchange sites on the soil particles for sodium, an index was developed to serve as a guide to evaluating this constituent of irrigation waters. This index is termed the Residual Sodium Carbonate or simply RSC[17]. It can be calculated by the following equation:

$$RSC = (CO_3^{=} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

where concentrations of all ions are in milliequivalents per liter of water as is the RSC.

The quality parameters and their values that are generally used to rank irrigation waters in terms of potential hazard to soil and plants are listed in Table 9. It should be noted that these values were developed for the western states where the annual rainfall is relatively low and therefore natural leaching is low. These values must be evaluated for the specific site

TABLE 9
Quality Classification of Irrigation Waters

	Level of Hazard			
Type of hazard	*Low*	*Medium*	*High*	*Very high*
Salinity				
Electrical conductivity, micromhos/cm	< 750	750-1,500	1,500-3,000	> 3,000
TDS, mg/l	< 500	500-1,000	1,000-2,000	> 2,000
Alkalinity and permeability				
SAR	< 3	3-5	5-8	> 8
RSC, mg/l	< 0	0-1.25	1.25-2.50	> 2.50
Toxins				
Boron, mg/l	< 0.5	0.5-1.0	1.0-2.0	> 2.0[a]
Chlorides, mg/l	< 70	70-140	140-280	> 280

[a] Hazardous for nearly all crops above 4.0 mg/l.

Source: Reference (17).

and conditions under consideration. Using the classification levels shown, the effluent water quality for Bishop (Table 6) would be rated as a "low hazard" except for the RSC which would be a "high hazard". Effluent wastewaters from most of the other plants listed in Table 3 through 6 would be classified as "medium to very high hazard", hence requiring special water and soil management procedures.

Gases in wastewater, other than those mentioned in regard to odors, are relatively unimportant in land application. Dissolved oxygen is usually depleted soon after wastewater is applied to the land. Atmospheric oxygen is relied upon for maintenance of aerobic soil conditions.

Biological Characteristics

Wastewater is teeming with microorganisms that are constantly changing its characteristics. The predominant microorganisms are bacteria.

Wasterwater may contain pathogenic organisms which cause diseases, such as salmonella gastroenteritis, typhoid and paratyphoid fevers, bacillary and ameobic dysentery, cholera, and infectious hepatitis[7]. Pretreatment is required to remove the bulk of these microorganisms from the wastewater. The presence of enteric pathogens is often ascertained by testing for coliforms. *E. coli (Escherichia coli)* are used as indicator organisms because they are more numerous and more easily tested for than pathogenic organisms. Tests have also been developed to distinguish between total coliforms, fecal coliforms, and fecal streptococci. These tests are important because many common soil bacteria are measured in a total coliform count. It is therefore important that a more specific test be used than the presumptive coliform test for measuring the degree of wastewater renovation for enteric bacteria in the soil system. The elevated temperature, fecal coliform test may be used to provide this differentiation[15].

Viruses are also present in sewage but in fewer numbers than bacteria. They are excreted from the intestine of man, particularly those infected with a viral disease. Approximately 100 serotypes have been isolated from the excreta of man and more will probably be found[1]. Because viruses are obligate parasites and require a host in which to live, they are often classified according to the host they infect.

Raw municipal sewage can be expected to contain from 10^6 to 10^8 total coliforms and from 480 to 1,677 PFU/L of enteric viruses[2]. Neither of the preceding quantitative values are indicative of total bacterial or total viral counts. The bacterial counts reflect only those bacteria which have many of the same physiologic characteristics as enteric bacteria. The viral counts reflect the limitations of today's techniques and may be one or more orders of magnitude low. Nonetheless they are relative and permit some evaluation of the effectiveness of our treatment processes and disinfectants. The expected removals or destruction of bacteria and virus by various treatment processes are listed in Table 10. As indicated virus removals up to 99 percent have been reported. As Sorber reports, however, there can remain about 50 virus particles per liter in chlorinated secondary effluent[14].

TABLE 10
Removal or Destruction of Bacteria and Virus by Different Treatment Processes

	Percent removal	
Process	*Bacteria*[a]	*Virus*
Fine screens	10-20	--
Plain sedimentation	25-75	0-3[b]
Chemical sedimentation	40-80	96-97[b]
Trickling filters	90-95	60[c] -84[b]
Activated sludge	90-98	0-88/99[d]
Chlorination of effluent	98-99 +	99[d]

[a] Source: Reference (10)
[b] Source: Reference (2)
[c] Source: Reference (3)
[d] 6.0 and 8.4 hours of aeration; respectively.

Effects of Pretreatment on Wastewater Characteristics

Conventional wastewater treatment begins with preliminary operations such as screening and sedimentation. Effluent from these operations is referred to as primary effluent. This primary effluent may be further treated by biological oxidation or by physical-chemical processes. Effluent from the more widespread biological processes, such as activated sludge, trickling filters, or oxidation ponds, is referred to as secondary effluent. Constituents removed by the various operations and processes in conventional treatment will be noted in the following discussion.

Primary Treatment

Coarse screens, present in nearly every treatment plant, remove large floating objects and rags. Fine screens are generally not used any more in sewage treatment because the smaller solids are removed by sedimentation and biological oxidation.

Sedimentation removes much (50 to 65 percent) of the suspended solid matter in the wastewater. Grit and gross settleable solids are often removed in grit chambers prior to primary sedimentation. BOD is reduced by primary sedimentation approximately 25 to 40 percent[10], and some organic nitrogen, phosphorus, and heavy metals are also settled out.

Primary treatment has a limited effect on biological characteristics. Sedimentation will remove most of the *Ascaris* eggs, but beef tapeworm eggs, hookworm, amoeba cysts, *Salmonella*, and viruses will not be completely removed[13]. Most of the dissolved and colloidal matter present in wastewater will not be removed in primary treatment.

Secondary Treatment

Biological oxidation results in the removal of colloidal and dissolved organics to a large extent. Additionally, some nitrogen and phosphorus are incorporated into bacterial cells and removed by secondary sedimentation. Most dissolved inorganics are not affected by secondary treatment. Secondary treatment provides an additional removal of bacteria and viruses by flocculation and secondary sedimentation.

Disinfection

Disinfection, the selective destruction of disease-causing organisms, may be accomplished using heat, ozone, bromine, iodine, or, most commonly, chlorine. Adequate disinfection requires complete and rapid mixing and minimum contact time. The presence of suspended solids hinders the process of disinfection; therefore, secondary effluent is more readily disinfected than primary effluent. The number of coliform organisms can be reduced by disinfection techniques from 10^6 organisms per 100 ml to less than 2.2 organisms per 100 ml.

Comparing Effluent Irrigation to Normal Irrigation

Stromberg[16] estimated the gross balance of several agricultural minerals added to the cultivated lands of Fresno County, California. He concluded that there was a deficiency of phosphorous and potassium being applied to the soil, compared to the amount removed from the field in the harvested product. Nitrogen, sulfur, chlorides, and sodium were being applied in excess of plant needs. Using data presented by Stromberg, together with Department of Water Resources data for water quality[5], Table 11 was constructed to compare normal agricultural conditions in Fresno County to a hypothetical application of secondary effluent. In all cases, the minerals would be applied at heavier rates for effluents. This does not prove that irrigation with secondary effluent is not feasible. It only means that the effluent should be distributed over more land and diluted by high quality waters,

TABLE 11
Hypothetical Comparison of Minerals Added by Irrigation plus Fertilization Versus Minerals Added by Effluent Irrigation

Constituent	*Fresh water*		*Fertilizers and amendments*[c] *lb/acre/yr*	*Total lb/acre/yr*	*Additions from effluent*[d] *lb/acre/yr*
	mg/l[a]	*lb/acre/yr*[b]			
Nitrogen	1.8	19	57	76	378
Phosphorus	--	--	6	6	--
Potassium	2.9	31	3	34	289
Sodium	11.5	124	--	124	2,240
Calcium	15.9	172	193	365	932
Magnesium	7.9	85	--	85	577
Chloride	10.8	117	1.6	119	2,380
Sulfate	5.9	64	462	526	1,920
Boron	0.1	1.1	--	1.1	16
TDS	155	1,675	720	2,395	13,450

---

[a] Composite of 50 percent groundwater and 50 percent surface water for Fresno County, California (Reference 4).

[b] Applied at 4 ft/ yr.

[c] Source: Reference (16)

[d] Pomona, California wastewater from Reference (6) applied at 8 ft/ yr.

receive additional treatment, or that provision must be made for adequate soil and water management practices when developing the program. The first alternative is in fact proposed for effluents from both of the cities of Fresno and Bakersfield, California.

A second hypothetical example was developed using irrigation water from the Colorado River, such as is used in Imperial County, California. Mineral additions from this poorer quality Colorado River water plus an allowance for fertilizer and soil amendments compare more closely to secondary effluent. Nevertheless, provision for good soil and water management practices would have to be provided for a successful operation (Table 12).

Many examples of irrigation with municipal wastewater attest to the fact that problems associated with chemical buildup can be resolved or, in fact, do not exist. However, as attempts are made to apply effluents to the land at higher and higher rates and under various climatic conditions, more precise knowledge must be available regarding the soil-water-plant system. How far can the system be stressed before failure occurs? What plants are available that can take up large quantities of chemicals, heavy metals and water without ill effects?

Areas of Suggested Research

Water will increase in TDS by 200 to 400 mg/l for each pass through the municipal system of water treatment, customer use, and wastewater treatment. It will also pick up substantial numbers of enteric bacteria and viruses. Therefore we must be prepared to accept this water and prepare it for ultimate absorption into groundwater bodies or surface water courses or for direct recycle to agricultural and industrial uses. As part of that preparation the following research is suggested.

1. What plants are available that would:
    a. Tolerate heavy amounts of water
    b. Take up large amounts of nitrogen and other nutrients
    c. Tolerate or take up high quantities of heavy metals.

    A list of such plants and their limitations should be available to those involved in planning and operating effluent irrigation systems.
2. What quantities of chemicals will selected plants take up under luxurious uptake conditions? How does the uptake affect the quality or potential uses of the plants?

TABLE 12
Hypothetical Comparison of Minerals Added by Irrigation with Colorado River Water Plus Fertilization versus Effluent Irrigation

	Fresh Water		*Fertilizers and amendments*[c]		*Additions from effluent*[d]
Constituent	*mg/l*[a]	*lb/acre/yr*[b]	*lb/acre/yr*	*Total lb/acre/yr*	*lb/acre/yr*
Nitrogen	0.3	3	57	76	378
Potassium	5.8	63	3	66	289
Sodium	125	1,360	--	1,360	2,240
Calcium	95	1.040	193	1,233	932
Magnesium	30	327	--	327	577
Chloride	124	1,350	1.6	1,352	2,380
Sulfate	314	3,420	462	3,720	1,920
Boron	0.17	1.8	--	1.8	16
TDS	856	9,330	717	10,047	13,450

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[a] Source: Reference (5)

[b] Applied at 4 ft/yr

[c] Average county-wide values for Fresno County, California from Reference (16).

[d] Pomona, California wastewater from Reference (6) applied at 8 ft/yr.

3. Can soil amendments be added to offset the buildup of various constituents of effluents? If so, what kind and what are their limitations?
4. What pretreatment methods are available for removing those constituents that cannot be balanced by luxurious plant uptake or by addition of soil amendments? What are the economic limitations of pretreatment methods?
5. What is the mechanism of virus inactivation and how can this mechanism by applied to effluent disinfection procedures?
6. What effect does high TDS effluent have on the adsorption of viruses in soils? What is the survival time of these adsorbed viruses?
7. Can superior indicator organisms to *E. Coli* be found in measure pathogen survival in soil?
8. What are the long effects of trace organics contained in wastewater effluents that are applied to the land?

CONCLUSION

In conclusion, decisions regarding the application of effluents to the land cannot be made based on generalities but must be made based upon actual water and soil quality data and environmental conditions such as rainfall, evaporation rates, and ranges of temperatures. Present knowledge is sufficient for establishing an effluent irrigation system in those cases where quality fits within the normally accepted limits for irrigation waters. However, in the remainder of the cases additional research is needed to produce tolerant plants and techniques necessary for complete management of the system.

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DISCUSSION

QUESTION: Tom Hinesly, Office of the Undersecretary of the Army. I would like to ask Mr. Pound if he can give us an example of where sewerage effluent has been used for irrigation and where we have had an example of a toxic condition being developed from heavy metals.

ANSWER: I don't know of any site where heavy metals has been in a toxic situation. I think the main problem in this whole subject, and the reason I brought it up is because people talk of it so much. The main problem that you find in the literature, of course, is the deficiency of heavy metal in soils, not excess of heavy metal.

QUESTION: William Bauer, Bauer Engineers, Chicago, Illinois. You mentioned the need to identify plants that would be able to take up increasing quantities of heavy metals. Have you given thought to simply the matter of accumulation of heavy metals in soils and banking them in effect over long priods of time.

ANSWER: Of course this happens. There is no question about it. I will have to back up on what I said earlier, because I did read, but cannot remember the reference, that somebody found that there was a metal toxicity. They then resolved the question simply by additional application of water and flushing the water, flushing the accumulation of either salt or heavy metals or both, down into the soil, away from the root zone. The common way that we eliminate the accumulation of salts and heavy metals in any irrigation system is by the flushing action of the water as it carries it down and so some excess irrigation is required. The normal practice of irrigation in California in the early part of the year, is to pre-irrigate substantially down several feet, then plant and this then saturates the soil, and prepares it for the coming season. If we want to get this material out, and this includes both the sodium and other cations, and we have to flush enough of this through the soil and work it out, so that they will sustain the viability of the soil as a medium for plant growth.

I am not an expert in the heavy metals subject and I have done only limited literature work in it.

COMMENT: Al Page, University of California, Riverside. I would just like to comment on what I prefer to call trace elements rather than heavy metals because we eliminate certain things when we talk about heavy metals. We eliminate certain things like aluminum, beryllium, and many others. As far as a trace element problem is concerned, I am sure that there are a number of instances whereby toxic effects of trace elements have been shown on plants where soils have been irrigated or sludges have been applied for a number of years. There are a number in England. There are some in Sweden. There are some in the United States. I think the most classic one is the Berlin and Paris sewerage treatment plants. In a study by Brody a rather acute copper and zinc toxicities to certain plants is shown. I think the accumulations of copper and zinc, if we can believe the data that are reported, are upwards of thirty or forty thousand parts per million in the surface of twenty centimeters of soil.

COMMENT: Bill Bauer, Bauer Engineers, Chicago. I would like to comment on the previous comment about this paper by Brody. One of our fellows was in Europe last December on vacation and we asked him to check into the Berlin and Paris sewerage farms to see what their current heavy metal problems were. He was unable to discover the existence of the Berlin farm. Evidently the land became too valuable and they no longer use it, but the Paris farm is still in operation. It has been in operation since 1885 and they still have about 7,500 acres irrigated, sandy soil. He asked them about the heavy metal problem and they didn't know they had one. They have very excellent growth of vegetables. The vegetables are the principal product and they market these in Paris for the most part, and the only heavy metal problem or trace element problem they remember was a deficiency of manganese which cut back production and they had to add some manganese. They were able to correct that situation, but they never heard of Brody and they didn't know they ever had a copper or zinc toxicity problem.

COMMENT: Belford Seabrook, EPA. Last July I visited the Berlin sewerage operations. They had about 700 acres under cultivation, however, the bulk of the water went to East Berlin, and they didn't have any clue as to what they were doing in East Berlin. I talked to them about all kinds of problems including those problems, and they said it was started in 1870 and that the current farming operation was started in 1895. Concerning a metals problem, they didn't know what I was talking about. They said they didn't think they had one. Nobody ever mentioned it to them. So, if they had one, certainly the people who had been operating it for 80 years aren't aware of it.

COMMENT: Bob Dean, EPA. On that Brody paper, if you read it carefully, it is conjecture on his part. And not actual going down and getting the stuff first hand. There was an assumption that was made about leaching these metals down into the groundwater, and I can immediately see some ears perk up, oh, we are going to poison our groundwater. It is very hard to get metals to move in groundwater. Boron will move. Chlorides and nitrates will move, but most of the metals stick to the soil and have a very low availability once they are on the soil.

COMMENT: Rufus Chaney, USDA. I hate to see that one go by without giving the example published by Blood in the *NAAS Quarterly Review.* He described among others, metal toxicity observations from sludge and effluents on, a sandy sewerage irrigation farm where they were growing a metal sensitive crop, sugar beets, and they had a low pH. They very easily solved the problem by liming, but that doesn't say the problem doesn't remain with the soil for subsequent pH drop.

COMMENT: Robert Williams, USDA, Washington, D. C. Just to change the subject slightly, Chuck Pound's paper is a real good argument it seems to me for having a good water treatment plant for the drinking water so that people have a quality water to drink, therefore you have a quality water to put on the land.

COMMENT: A. Kaplovsky, Rutgers University. We always had a truism that treatment is only as effective as your handling capability. So, if you are going to take out those thousand parts per million dissolved solids at one end, you are going to have to find some place to put them, and that is the problem.

CHAIRMAN: Darwin Wright, EPA. I guess we really haven't addressed the problem of treatment plant sludges, maybe we should keep that in mind when we enter into our workshop sessions on sludges and utilization of sludges.

A Regional View On the Use of Land for Disposal of Municipal Sewage and Sludge

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I am pleased to have this opportunity to participate in this very timely and most important research needs workshop. The recycling of municipal sludge and effluents to the land is a most appealing conservation concept, but as the extensive list of topics on the agenda illustrates, it is also a concept which is plagued with a wide variety of problems, and this despite the fact that the concept has been around as long as man himself. It is encouraging to see so many different skills and disciplines and interests represented here, and I am sure that this program will enable all of us to become more knowledgeable in the state-of-the-art of land disposal.

I spoke of this workship as being timely. From my view, the concept of recycling as a conservation practice, appealing as it may be, has been in conflict with the throw-away philosophy of our society in which planned obsolescence has become a way of life. If we, as a society, have such a disregard for the value of material things, how, then, can we convince the decision makers and the public that recycling of such an unappealing material as sewage is a viable alternative to the prevailing attitude of getting rid of, i.e., disposing of waste products? I would suggest that one of the ways is through a symposium such as this, which can capitalize on what I sense, hopefully, is the beginning of a change in national attitude. There is new concern for the environment; there is new concern for the conservation of energy; and there is a growing recognition that our resources are finite. These are only a few of the trends that combine at this point in our history to make the task of gaining public acceptance of this concept of utilization of wastes, as opposed to simply trying to get rid of them, much less difficult than it would have been only a few years ago.

Aside from posing such philosophical concerns, I see my role as a regional participant in this workshop as providing you with a regional insight into the use of land for municipal waste treatment.

While research, per se, is not a responsibility of the Regional Offices, the Regional Administrator does have on his staff a small number of research experts who provide him with the necessary liaison between the nationally directed research activities of EPA and the Regional Office. The Regional Office, as a whole, does become involved in prioritizing proposed regional research needs, in monitoring demonstration projects, and each region has a Technology Transfer Activity. However, I will speak primarily of those regional functions through which the practical application of new Municipal Waste Treatment Works Projects will proceed without Federal assistance, this practical application is accomplished mainly through two programs—through Water Quality Management Planning and through the Construction Grants Program.

Under Section 303 of the Amended Federal Water Pollution Control Act of 1972, each State is required to have a continuous planning process consistent with the Act. The interim regulations governing this process that relate to this discussion specify that the process shall provide the States with the water quality assessment and program management information

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necessary to make centralized, coordinated water quality management decisions, that it shall provide the strategic guidance for developing the Annual State Program, and that the process will encourage water quality objectives which take into account overall State policies and programs, including those for land use and other related natural resources. As part of the overall State strategy, this planning process, among other things, is to provide for the development of basin plans, is to provide a mechanism for determining State priorities for construction of publicly owned treatment works and is to provide for processing of waste-water discharge permits.

The planning process is designed to meet the three milestone dates set by the law; these are 1977, 1983 and 1985. As a matter of first priority, planning is designed to meet the requirements of 1977 for "best practicable treatment" or compliance with water quality standards, by classifying the waters of the States to determine required treatment levels for the purpose of issuing permits under the National Pollutant Discharge Elimination System (NPDES). As distinct from requirements as established for 1977, the law also established national goals of fishable, swimmable waters by 1983, and the elimination of the discharge of pollutants by 1985. Long range planning will be keyed to these goals.

As a prerequisite for a municipality to be considered for a Federal Construction Grant, a project must be in conformance with the State's Water Quality Management Plan for the area, and the plan must also be approved by the Regional Administrator. The specific project must also be certified by the State as entitled to priority over other eligible projects from the State's allocation of Federal Construction Grant Funds

Part of the guidance for Water Quality Management Planning is contained in Title II of the Act entitled "Grants for Construction of Treatment Works."

Title II of the Law states that, "waste treatment management plans and practices *shall provide* for the application of the "best practicable waste treatment" technology before any discharge into receiving waters, including reclaiming and recycling of water and confined disposal of pollutants so they will not migrate to cause water or other environmental pollution, *and* shall provide for consideration of advanced waste treatment techniques." Title II further states, "the administrator shall encourage waste treatment management which results in the construction of revenue producing *facilities for:* (1) the recycling of potential sewage pollutants through the production of agriculture, silva culture, or aqua culture products or any combination thereof; (2) the combined and contained disposal of pollutants not recycled; (3) the reclamation of wastewater; and (4) the ultimate disposal of sludge in a manner that will not result in environmental hazards." The Act goes on to further state that the administrator shall encourage waste treatment management, "which results in *integrating* facilities for sewage treatment and recycling, with facilities to treat, dispose of, or utilize *other* industrial and municipal wastes . . ." Section 208 of Title II provides for development of area wide waste treatment management plans and requires that any such plan will provide for any requirements for the acquisition of *land for treatment purposes.*

Section 403 of the Act deals with disposal of pollutants in the ocean and instructs the administrator, among other things, to develop *other* possible locations and methods of disposal or recycling of pollutants, *including land based alternatives.* Section 405(a) specifically prohibits the disposal of sewage sludge from the operation of a treatment work in a manner which would result in any pollutant from such sewage sludge entering the navigable waters except as provided under a permit.

The new law also made a significant change in the definition of treatment works, which is of vital importance to the recycling of municipal sewage and sludge to the land. Contrary to the previous law, federal financial participation may now be provided for "site acquisition of the land that will be an integral part of the treatment process or is used for ultimate disposal of residues resulting from such treatment." The key question for any land disposal project for purposes of Federal participation in land costs is, "Does the use of the land itself result in the treatment and renovation of municipal wastewater?" Since solid materials are one of the products of wastewater treatment and can, under proper conditions, be applied to the land, the application of municipal sludge to the land can be therefore considered an integral part of land treatment. Deposition of sludge in dumps, it should be noted, is not considered treatment. This new definition of eligibility opens up a whole new opportunity for consideration of recycling of municipal waste to the land, since land utilization for waste treatment now becomes much more competitive, cost wise, with other conventional treatment methods where federal funds are used. This opportunity has been further enhanced by federal assistance in the costs of relocation of persons displaced by a project.

There are other sections of the new law that incorporate the disposal-utilization concept, and as you can see from these references cited, one of the central themes of the amendments is also an effort to redirect our national thinking away from the almost exclusive preoccupation with disposal of sewage to the nation's waters. In the alternative the new law provides direction and incentives for the consideration of the use of land for recycling, reuse and utilization of sewage and sludge.

We in the Regional Office having responsibility for review of State Water Quality Management Plans, and Construction Grant Projects are guided by this new national policy. We support and encourage the continued development and practice of successive water reclamation, reuse, recycling and recharge as major elements in water resource management. At the same time reclamation systems must be designed and operated so as to avoid creating human health hazards or damage to the environment.

Environmental compatibility must be a major consideration in the selection of any method of waste treatment and all projects for which federal assistance is sought must have had a formal environmental assessment prepared by the applicant. These assessments are evaluated by EPA on the basis of EPA regulations for carrying out the provisions of the National Environmental Policy Act of 1969. EPA's evaluations result in either of two actions. One can be the issuance of a notice of intent to file an environmental impact statement where the assessments are either considered to be inadequate *or* where there is *significant* environmental controversy. The alternate action is the issuance of a "negative declaration" where the assessment is considered satisfactory and there is no significant environmental controversy.

While environmental compatibility must be a major consideration in the selection of any method of waste treatment, the use of land for waste disposal always seems to create more environmental controversy than any other process. From our experience in Region V, we expect that all land disposal projects will require a Federal Environmental Impact Statement. This is not true for projects involving more conventional methods of waste treatment and is an indication of a lesser degree of public acceptance of land disposal as a viable alternative. This suggests that one of the major challenges before this workshop is to develop techniques for land disposal that can compete environmentally with conventional processes. To cite one example where major controversy arose which did not involve EPA, the Corps of Engineers in connection with a long range waste management study of the Chicago Metropolitan Area proposed, as one alternative, acquisition of 445,000 acres of land in central Indiana for application of Chicago's wastes. This provoked intense opposition and reaction by indignant Hoosiers. The final report of this study is not issued but I understand there has been considerable modification to this alternative which apparently was due in part to the reaction the proposal received.

Because of the impending large outlay of federal funds for the construction of municipal treatment works, EPA is concerned with getting the most out of this federal investment. The FWPC Act Amendments raised federal financial participation to 75 percent of the eligible costs and vastly increased the amount of funds available. Cost-effectiveness therefore becomes a major consideration in the selection of a waste treatment process. A cost-effective analysis must accompany each application for a construction grant. A principal element in cost-effective analysis is a comparison of alternatives, and proposed guidelines for cost-effectiveness will require that the analysis compare at least two methods for a particular situation.

Cost-effectiveness does not necessarily mean least cost, but the most economical method will always have an overwhelming advantage. Here again is a challenge for this workshop.

I would now like to consider briefly the extent to which land disposal is being used. Accurate information on land treatment systems is difficult to obtain and evaluate. As a generalization we do know that only a small percentage of municipal wastewater is treated on the land, perhaps no more than three or four percent. This seems to be quite low, but on the other hand, growth of land treatment systems in the United States will take place in a productive, environmentally compatible, and cost-effective manner only if enough information and knowledge of how the land functions as a wastewater treatment system is obtained. This knowledge must be of a depth and quality that will permit sound design and reliable performance prediction.

EPA has in the past and is now supporting research, development, and demonstration programs to acquire this knowledge and this also is a major challenge to this workshop. Several well known land disposal projects in Region V have had the benefit of research grants. These are the Fulton County Sludge Utilization Project and the Muskegon, Michigan Spray Irrigation Project. In addition, the Muskegon Project has also received major construction grant support. Once in full operation this project should, through the research, development, demonstration grant, provide a large amount of performance data that is so badly needed for land treatment systems. The Muskegon Project, from the non-technical standpoint, already has provided an excellent example of effective regionalization in an area with relatively complex governmental relationships.

I have attempted in this brief discussion to present a general picture of the Federal, State and local cooperative actions necessary to bring a municipal waste treatment project to completion. To further summarize, we have new national water pollution control legislation which challenges conventional methods and conventional thinking. It sets new requirements and goals that truly provide the impetus for making the 1970's the decade of the environment. Certainly the timing of this workshop is appropriate to meeting the particular challenge in the law with regard to finding land based alternatives for the handling of municipal wastewater. We in the EPA Regional Offices look forward to the practical application of the results of your deliberations during this meeting.

The Physical Processes In the Soil as Related to Sewage Sludge Application

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ABSTRACT

The physical processes in the soil are discussed with particular reference to sewage sludge application.

Adding sewage sludge initially increases the hydraulic conductivity of a soil, but the conductivity later decreases. This decrease appears to be due to clogging of soil pores by microbial decomposition products.

Soil structure afts soil water, soil air, mechanical impedence and root distribution. Organic matter, through the activity of microorganisms, increases soil aggregation. Sewage sludge application increased the stable aggregates 16 to 33 percent.

The low oxygen and high carbon dioxide contents in the soil that result from high sludge application can reduce root growth, nutrient uptake and plant growth. Other gas products of decomposition, such as methane and etheylene, can be detrimental to plants.

INTRODUCTION

Soil physical processes are related to the mechanical properties of the soil. These processes chiefly depend on:

1. Texture or size distribution of particles.
2. Structure or the arrangement of particles.
3. Amount and type of organic matter.
4. Both amounts and kinds of exchangeable ions.
5. Mineralogical properties, particularly the kind and amount of clay.

The physical properties influence:

1. Water retention and movement.
2. Aeration.
3. Plant growth - root penetration, plant development, yield, water and nutrient uptake
4. Biological processes - gaseous production; organic matter decomposition; activity of microorganisms and other soil biota.
5. Movement of salts, nutrients, and organic compounds such as pesticides.
6. The microclimate of the soil - heat flow and temperature.

The topics discussed in this paper will involve:

1. Soil water relationships - Energy relationships; factors affecting water retention; and water movement through soil.
2. Soil structure - Concepts and factors affecting the structure of soils.
3. Soil air - Diffusion and composition.

Soil Water Relationships

State of Water In Soil

Water in the soil can contain energy. This energy is essentially potential energy due to position or internal condition. The kinetic energy of soil water is negligible. The total soil water potential (ψ) or energy per unit quantity is defined as "The amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric pressure to the soil water (at the point under consideration)"[1]. Essentially this means that energy must be expended to move water from one location in the soil to another at standard conditions.

Total potential of soil water consists of four components:

1. Gravitational potential (ψ_z)

   This is the potential due to the gravitational force field and is dependent on the elevation of water.

2. Pressure potential (ψ_p)

   This is the potential due to the overall pressure being different from atmospheric pressure. It can be positive if the pressure is above atmospheric, or negative if the pressure is below atmospheric.

3. Matric potential (ψ_m)

   This potential results from the capillary and adsorptive forces due to the soil colloidal or soil matrix system. This potential has also been referred to as matric suction or soil water suction. Matric potential is equivalent but opposite in sign to matric suction.

4. Osmotic potential (ψ_s)

   This potential is a result of the presence of solutes in soil water, which in effect lowers the potential energy.

Soil Water Retention

Water entering a dry soil surrounds soil particles and fills the capillary pores. As the initial pores are filled, the water moves into successive pores. As the volume of water diminishes, the rate of movement diminishes. Thus, as the suction increases and the soil becomes drier, the conductivity of water decreases.

The relationship between soil water potential or energy and soil water content is termed soil water retention or soil moisture characteristic curve (Figure 1). As the water content decreases, the remaining water is held more tightly by the soil particles, i.e., the adsorptive and capillary forces become greater.

Plant roots must exert energy to remove water from soil. The drier the soil, the greater the amount of energy that is needed. Thus, as the moisture content decreases, the soil water potential decreases.

The soil water retention curve is influenced by soil texture (Figure 2). The greater the clay content, the greater the water content for a given potential or suction. Soil structure also affects the shape of the soil water retention curve. This is especially true in the low suction range, i.e., high water content. An aggregated soil will have large pores, whereas a compacted soil has a lower total pore space and a lower volume of large pores.

The addition of five percent sludge to a silt loam soil shifted the water retention curve and increased the amount of water retained at different suction

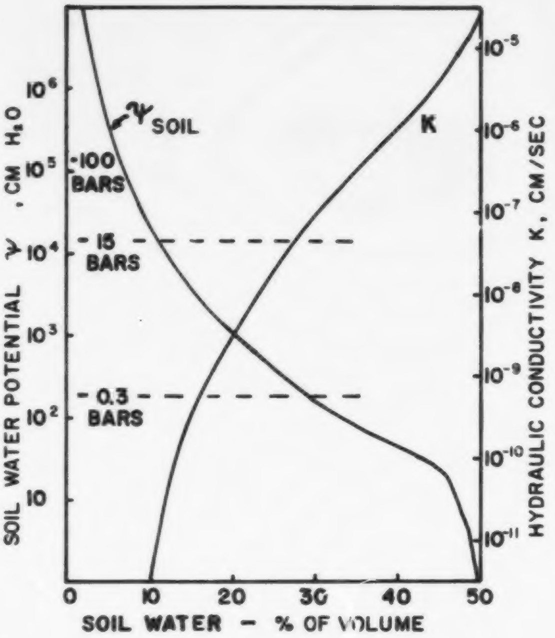

Figure 1: Soil Water Retention Curve*.

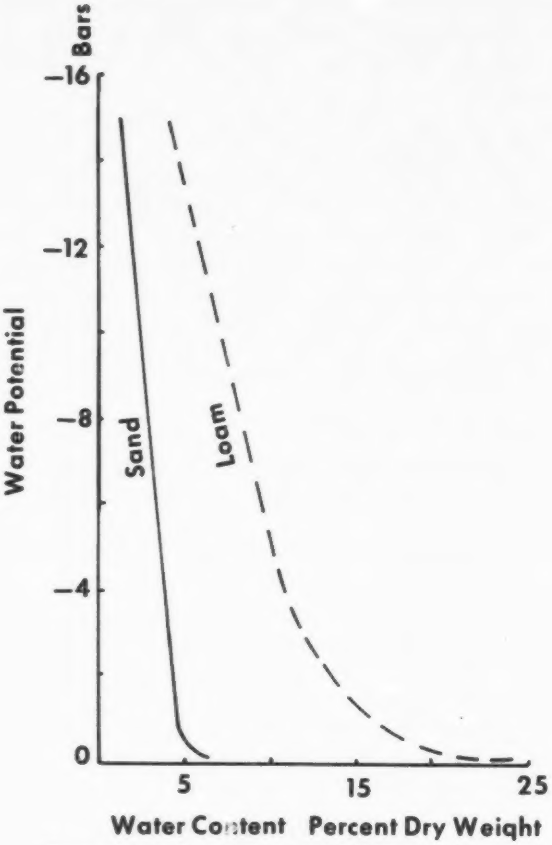

Figure 2: The Effect of Texture On Water Retention.

values (Figure 3). Similarly, adding sludge compost (Figure 4) increased the water content as various suction values.

Attempts have been made to relate to the state of soil water to the water available for plant growth. Two values have been used to indicate the upper (wet) and lower (dry) limit of water in the soil that is available to plants. The upper (wet) limit has been called field capacity and the lower (dry) limit, the wilting point.

Field capacity has been considered as the water content at which internal drainage (gravitational flow) ceases. However, it must be recognized that water flow does not cease. Hence, no single value is valid. The water potential value commonly used for field capacity is -0.33 bar. Laboratory measurements of field capacity are not reliable indicators of field conditions. Soil structure, texture and profile characteristics affect water retention in this low suction range. Hence, field capacity should be measured in the field.

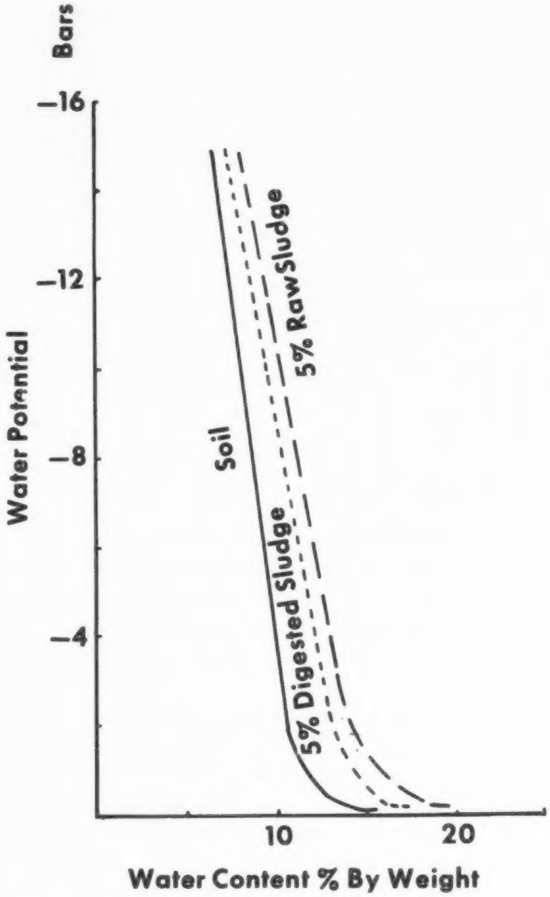

Figure 3: The Effect of Sewage Sludge On Water Retention.

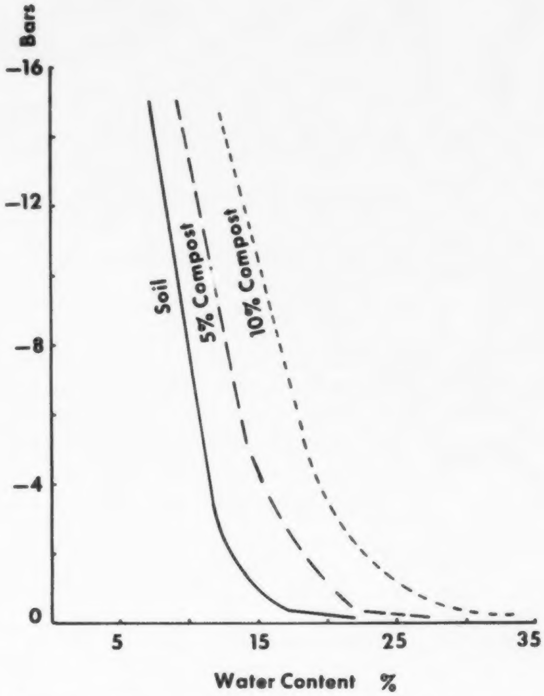

Figure 4: The Effect of Sewage Compost On Water Retention.

The second value, denoting the lower limit or dry state of a soil with reference to plant growth, is the wilting point. This condition is designated as the soil water content at which plants wilt and will not recover. Again, it must be realized that the wilting point is not a constant. The water potential value arbitrarily used for wilting point is -15 bar. Because this value is in the dry region, large increases in suction produce only small changes in soil water content and laboratory measurements can be used to indicate this value.

The soil water content between the value designated for field capacity (usually taken as -.33 bar ψ) and wilting point (-15 bar ψ) has been termed the available water. However, the above values are not constant and the field water cycle is dynamic, involving the soil, plant and atmosphere. Thus, rather than using the term available water, it is preferable to designate the specific suction or potential values used for comparative purposes.

Water Movement Through Soil

Water moves through soil in response to gradients in the hydraulic potential. In other words, the volume of water per unit cross-sectional area is proportional to the driving force in the direction of flow. Mathematically this is expressed as follows:

$$J_w = K_w \frac{\partial \psi}{\partial S}$$

where:

J_w = flux density = $\frac{Q}{At} = \frac{\text{Volume}}{\text{Area x Time}}$

K_w = hydraulic conductivity

$\frac{\partial \psi}{\partial S}$ = hydraulic potential gradient = $\frac{\text{hydraulic potential}}{\text{direction of flow}}$

This is known as Darcy's Law and applies to water movement under saturated flow. The hydraulic conductivity (K) depends on soil characteristics and the fluid properties. The soil characteristics that affect K are texture, porosity, distribution of pores, and tortuosity. The fluid properties are density and viscosity.

In practice, K is separated into two factors; intrinsic permeability of the soil (k) and fluidity of the fluid (f).

The permeability of the soil is therefore related to the hydraulic conductivity as follows:

$$K = \frac{Kv}{\rho g}$$

where:

k = intrinsic permeability (cm^2)
K = hydraulic conductivity (cm/ sec)
v = viscosity (dyne sec/ cm^2)
ρ = density (gm/ cm^3)
g = gravitational acceleration (cm/ sec^2)

When a soil is saturated, all of the interconnecting pores are available for water conduction and hydraulic conductivity is at a maximum (Figure 1).

Unsaturated flow is difficult to describe quantitatively. The pores in an unsaturated soil are only partially filled with water and the remaining pore space is filled with air. The hydraulic conductivity is affected by the water content of the soil. Thus, as the soil drains and the large pores are emptied of water, the gravitation potential becomes less important and the matric potential becomes more important. As the soil water content and the soil matric potential decrease, the hydraulic conductivity decreases vary rapidly. The hydraulic conductivity varies for soils of different textures (Figure 5). Adding sludge to soil initially increases the hydraulic conductivity, but later it returns to the original value (Figure 6). Johnson[4] found a similar relationship for crop residues, and attributed the decrease to clogging of pores by microbial decomposition products.

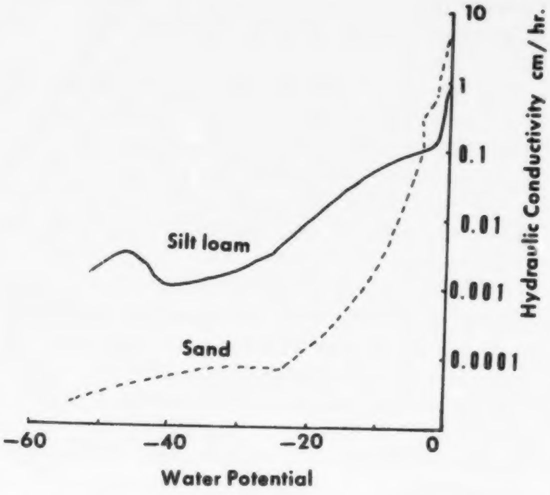

Figure 5: The Effect of Texture On Hydraulic Conductivity.

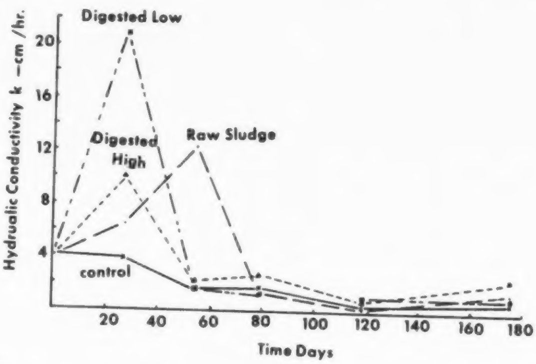

Figure 6: The Effect of Sewage Sludge On the Hydraulic Conductivity.

Infiltration

Infiltration of water into soil depends on initial water content, soil water potential, texture, structure, and homogeneity or uniformity of the profile. Changes during wetting, such as deterioration of surface structure and sealing of soil pores, will reduce infiltration.

When water is applied, the surface of the soil becomes saturated for several centimeters. Below this region is a transmission zone which is nearly saturated. Below this zone is a wetting zone where soil moisture decreases rapidly to the wetting front. Sewage sludge and sludge compost will increase water infiltration by providing greater soil pore space and decreasing the potential of surface sealing.

Soil Structure

Soil structure is the arrangement of soil particles. Soil particles stick together to form clusters, aggregates, and clods. It is the relationship of these aggregates through their effect on the soil pore space that influences the biological processes in the soil. Soil aggregates and their arrangement affect soil water, soil air, mechanical impedence and root distribution.

The formation and stability of soil aggregates depend on the soil particle size distribution, organic matter, cations and soil management. Because of the multitude of arrangements that can be present in the soil, it is impossible to describe soil structure directly. Generally, it is evaluated in terms of changes in structure and the effects that these changes have on aeration, aggregation, mechanical impedence, and infiltration.

Organic Matter

Organic matter influences soil aggregation through the activity of organisms, primarily microorganisms. Hubbell and Staten[3] found that fungi produced the most aggregates, actinomycetes produced an intermediate number, and bacteria produced the least.

Adding sewage sludge and incubating for 175 days increase the stable aggregates from 16 to 33 percent (Figure 7). Although rapidly oxidizable organic matter may produce a desirable soil structure, continual additions of organic matter will be necessary to maintain this structure as the cementing agents are decomposed. If no further organic matter is added, the residual organic matter will decompose slowly with some deterioration of soil structure[5].

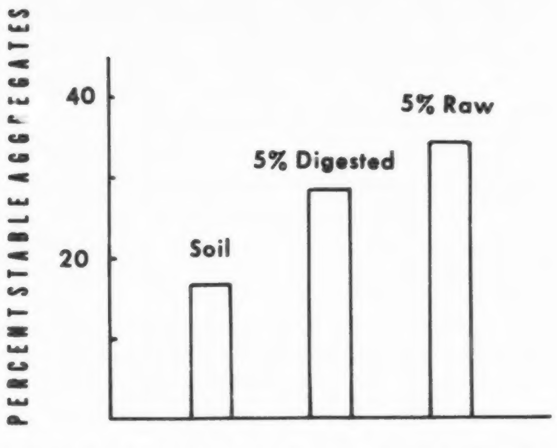

Figure 7: The Effect of Sewage Sludge On Stable Aggregates[5].

Water

Soil aggregates tend to break up when wetted. This is caused by differential expansion; that is, the outside of the aggregate expands while the inside is still dry. If aggregates are submerged in water, the air is entrapped and the aggregates explode.

The beating action of raindrops disrupts aggregates. The kinetic energy of rainfall is considerable and depends on drop size. Figure 8 illustrates the effect of two drop sizes on porosity of a crust. Crusts formed under small drops were considerably more porous than those formed under large drops regardless of the rainfall rate. Crusts formed as a result of raindrop impact have a dense layer 2 to 3 mm thick.

Erosion, which is the end result of dislodgement and transport of soil particles, can be reduced markedly by the addition of organic matter such as sludge or compost to soil. Infiltration can be increased, thus reducing the amount of water available for transport of soil particles. Furthermore, the aggregates are more stable and resistant to breakdown. A compost mulch also will reduce the energy of raindrop impact.

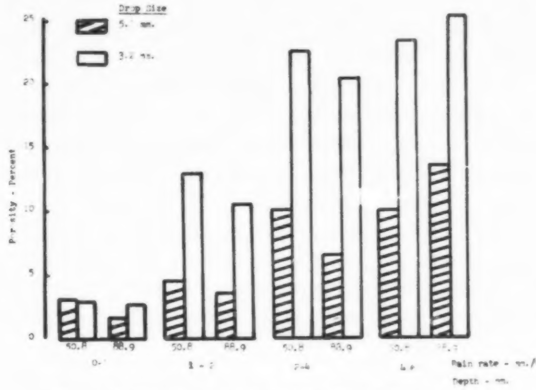

Figure 8: Porosity of a Soil After Ten Minutes of Rain.

Soil Aeration

The addition of sewage sludge to soil markedly affects the diffusion of gases and the composition of the soil atmosphere.

Diffusion of Gases

Gases diffuse through the soil when there are differences in partial pressure or concentration of gases. Conditions must be present that allow the gases to move out or through the soil. Thus, diffusion of gases and, consequently, the composition of the soil atmosphere depends on the porosity of the soil. In turn, the water content and the bulk density of the soil affect the aeration porosity.

Composition of Soil Atmosphere

The soil atmosphere generally contains 0.25 percent carbon dioxide, 20.73 percent oxygen and 79.02 percent nitrogen. Changes in the soil atmosphere affect the biological processes of the soil.

Plant Growth. Root development is restricted when oxygen levels decrease and carbon dioxide levels increase. Plant species vary in their response to changes in the soil atmosphere. For example, tomatoes are sensitive to low oxygen concentrations, barley is less sensitive, and rice is relatively insensitive. Plant growth also may be affected by the production of toxic gases such as methane and ethylene.

Aeration influences the uptake of water and nutrients. High carbon dioxide concentration and low oxygen concentration greatly reduce water absorption. Aeration affects potassium uptake, particularly under conditions of high carbon dioxide. Other elements such as iron, nitrogen, calcium, phosphorus and magnesium are also affected but to a lesser degree. Under anaerobic conditions (less than two percent oxygen) ethylene gas can be produced and may injure crops[8]. Russell[7] indicates that other gases such as methane and hydrogen sulfide may accumulate in the soil during anaerobic decomposition and reduce root growth. The composition of the soil atmosphere is primarily influenced by the presence of organic matter and its decomposition.

Figure 9 illustrates the changes in carbon dioxide, methane and oxygen below a trench filled with sewage sludge. The high methane and carbon dioxide and the low oxygen levels could restrict root growth and development and reduce plant growth. Figure 10 shows the restricted root growth surrounding a trench filled with raw sludge. Root penetration was considerably better with digested sludge (Figure 11).

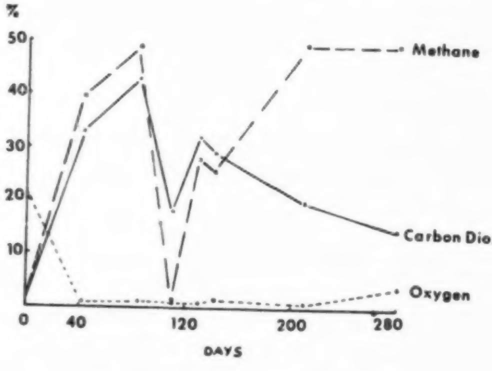

Figure 9: The Effect of Sludge On Gages.

Biological Changes. Aeration affects the microbial population. The products of anaerobic decomposition are different from those of aerobic decomposition[10]. The different microbial populations will affect such processes as nitrification and denitrification. Anaerobic conditions are conducive to denitrification, whereas aerobic conditions favor nitrification.

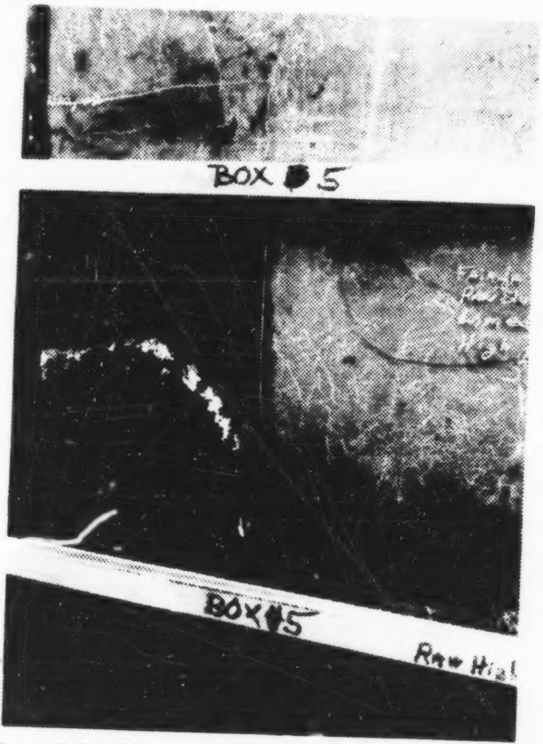

Figure 10: The Effect of Raw Sludge In a Trench On Root Growth.

INTERPRETIVE SUMMARY

Sewage sludge and sewage compost increase the retention of soil water. Adding sewage sludge initially increases the hydraulic conductivity of a soil, but the conductivity later decreases. This decrease appears to be due to clogging of soil pores by microbial decomposition products.

Soil structure affects soil water, soil air, mechanical impedence and root distribution. Organic matter, through the activity of microorganisms, increases soil aggregation. Sewage sludge application increased the stable aggregates 16 to 33 percent.

Incorporation of sewage sludge markedly influences the soil atmosphere. The low oxygen and high

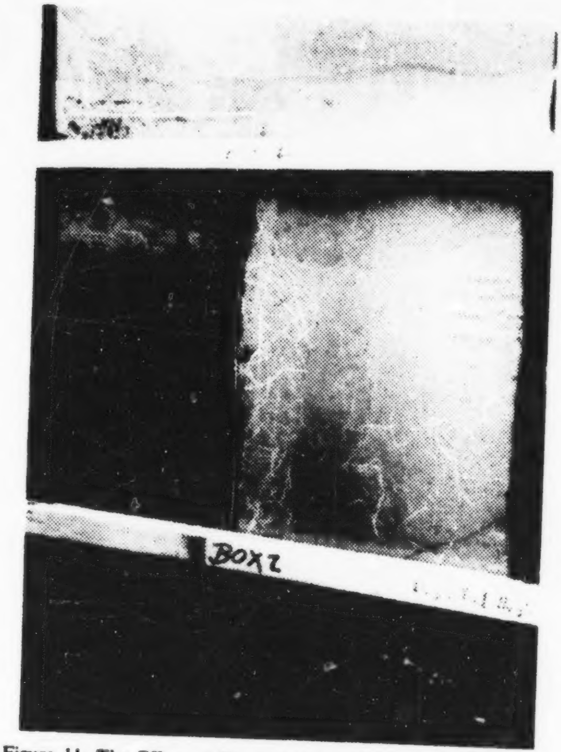

Figure 11: The Effect of Digested Sludge In a Trench On Root Growth.

carbon dioxide contents that result from high sludge application can reduce root growth, nutrient uptake and plant growth. Other gas products of decomposition, such as methane and etheylene, can be detrimental to plants.

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Physical Changes to Soils Used for Land Application of Municipal Waste—What Do We Know? What Do We Need to Know?

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ABSTRACT

The beneficial effects of sludges on changing soil physical properties is known while little is known about the effects of heavy effluent loading. The transfer of design experience from ordinary agriculture has some difficulties. Therfore the greatest research need in this area is field experimentation to develop soil and crop management systems to optimize the amount of effluent applied while maintaining maximum yields of agricultural crops. Other research should consider the effects of high sodium concentrations in both sludges and effluents and how to avoid or overcome these effects.

INTRODUCTION

The physical changes in soils due to the application of municipal waste will vary greatly depending on the kind of soil, type of waste and quantity of waste applied. Soils can range from coarse textured, single grained and quite inert to fine textured, structured and very reactive. Municipal waste can range from dry sludge to a dilute effluent. Application rates can range from minimal application of sludge for nutrient additions to massive applications of sludge or effluent for disposal or "dumping". In this discussion it is assumed that neither the very light or the very heavy application of waste is our concern but an optimum amount of waste to allow the utilization of the land for agriculture or some other useful purpose. At the same time the goal is to maximize the amount of waste applied or minimize the amount of land used. Because of the wide differences between the physical properties and reactions of sludges and effluents, they will be considered separately.

Sludge

Manures which in some ways can be considered as similar to sludges have been used for millenia on soils. Their physical effects and reactions with soils are quite well understood. There is considerable literature available on effects of sludges on the physical condition of soils. Sludges are advertised and sold on the basis of their soil conditioning effects and fertilizing nutrients.

In coarse textured, single grained soils the sludge will condition an otherwise inert soil by its near presence as a surface active and water absorbing additive. The soil water properties are improved, the water held at any tension is increased, and the soil nutrient sorption capabilities are increased resulting in a much more productive soil. In fine textured soils which are capable of developing a structure but are low in organic matter, sludge can supply the organic matter for the formation of a stable structure which could increase the infiltration and permeability rates, decrease the bulk density, increase the aeration porosity and improve the productive capacity of the soil.

The amounts of sludge used in most cases is more apt to be limited by the potential of the amended soil to leak nutrients than for them to be overloaded physically. This means that on most soils in a humid climate 10 to 20 tons per year would be the maximum that can be used. In very bad situations where the

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physical problems are critical such as mine spoil, large quantities of sludge produce the immediate physical soil improvement which is required for reclamation.

There are several precautions that should be mentioned. Sludges that have large quantities of sodium can have a deleterious dispersing effect on structured soils and should be applied in small quantities, leached before use or avoided. Sludges will not have any beneficial effect on organic soils or soils that are high in organic matter.

There are at least two areas for further research, one concerns the amounts of a sludge that can be used to improve a particular soil in its particular climate, the other which is probably more important concerns the development of a best method for spreading and incorporating a particular kind of sludge into a particular type of soil to bring about the best physical condition of the soil at a reasonable cost.

Effluent

The consideration of the changes in soil physical conditions due to effluent additions is more difficult because there has been less research in this area. Also many of the soils to which effluent is now being applied are coarse textured and would not be expected to change physically. However, the best soils physically or hydraulically are the coarse textured soils which give the poorest chemical treatment. The medium and fine textured soils which have a greater capacity to treat effluent have a lower hydraulic capacity. There is the tendency to underdesign these systems and overload the soils hydraulically which will reduce crop yields or even destroy the crops.

Design data could come from agricultural drainage and irrigation design. Actually agricultural drainage design has severe economic constraints and is designed to avoid calamities. Usually the design allows for some yield reduction under severe weather situations. Irrigation design is based on the addition of water to a dry soil in sufficient quantities to supply a growing crop. Both of these practices are quite different from adding the maximum quantity of effluent, which is often higher in salts and solids to a soil and grow economic crops.

In effluent farming the usual drainage criteria cannot be used continuously during a growing season as this would allow poor aeration conditions and greatly reduce crop yields. At the same time effluent farming will require the addition of effluent to moist, not dry, soils which may have much lower initial infiltration rates and permeability than experienced in normal irrigation.

The hydraulic properties of medium to fine texture soils decrease when moist. Under continual infiltration the rate of infiltration drops. Moist subsoils can have permeabilities that are a fraction of permeability they would have when partially dried by drainage and by roots activity. These changes are due to the hydration and swelling of the natural peds under continually moist conditions which reduces the large pores. If organic matter is present, oxidation-reduction potentials can drop and cause further structural deterioration. Upon drying the peds shrink, the structure is stabilized and the infiltration rates and permeabilities recover. Effluent farming therefore will have to include drying cycles for crop and soil manipulations and some soils may need drying cycles for the recovery of desirable physical soil conditions.

There is a very wide diversity among soils. The assumption that because the soil on the Pennsylvania State Effluent Project took two inches of effluent per week therefore all intermediate texture soils will do the same is not valid.

The greatest research need in land treatment of effluent as it effects the physical changes in soils and crop yields is for field experiments with effluent application on medium to fine texture soils which have adequate artificial drainage. The objective of this research should be to maximize the quantity of effluent that can be applied and still maintain crop yields.

Another potential problem is the high sodium content of many effluents. Sodium can cause the clay in the soil to disperse, the structure to degrade and the surface soil to seal. This causes the infiltration rate and permeability to drop markedly. There is a wealth of data in this area developed for our arid regions that can be applied elsewhere however some experimentation with the soils involved and the influence of natural rainfall should be studied.

Effluents that contain considerable soils could cause pore plugging problems but reductions in application rates and allowing for drying cycles should reduce this problem. Effluents that contain considerable BOD could cause an increase in carbon dioxide and a reduction in oxygen in the plant root zone. This could cause an aeration problem for plants growing on the soil if the application rate is not reduced.

Sewage

Because sewage has more organic matter than effluent and is more biologically active from a physical soil point of view it is a better soil amendment than effluent alone. The solids might cause a plugging problem but the extra organic matter would have a greater soil conditioning or soil structure stabilizing effect similar to the effect of manuring. The development of processes to remove the public health hazard of land treatments of raw sewage would greatly simplify the present systems which remove the soil conditioning BOD from the effluent and concentrate other materials, often to toxic concentrations, in the sludge.

CONCLUSIONS

There is more known about sludges and their effects on changing the physical properties of soil than there is about effluents. Field experiments to determine the maximum amounts of effluents that can be applied to medium textured soils and produce good to maximum crop yields in combination with existing rainfall are necessary. The influence of sodium in effluents or high sodium sludges should be researched to determine the limits of particular soils or practices that might be used to accomodate time.

DISCUSSION

QUESTION: Ray Harris, United States Forest Service. I was interested in the comment on sands and it was also eluded to by several of the other speakers, and I know that when we start applying the large rates that we are going to have, of course, a chain system. We are creating what we might call a new soil or a pseudosoil whereby we are changing all the properties that the original soil had. Don't you think that over a period of time with proper management, and these are long term things, that we would end up in sands with a much better renovator with a system that has a lot of properties of finer soils, but because of organic matter has better renovation built in? Of course aeration ability to accomplish the purposes that we are about to do since in the course of soils the water is much more viable. The sands in the long term run might be our better soils for renovation purposes.

ANSWER: I think that you are right. Using the effluent on sands we will build these soils up, but if what my chemist friends say is true, these will begin to leak nutrients. Phosphorous will leak from these soils very readily. Then I think we are in a problem and this is why we have to back off on sands. Hydraulically, they are good, but renovatively, I think they are not so good.

Soil Microbiological Aspects of Recycling Sewage Sludges and Waste Effluents on Land

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ABSTRACT

The biological component of soil which includes bacteria, actinomycetes, fungi, algae and soil micro- and macroanimals makes significant contributions to waste recycling by decomposing waste organic compounds; eliminating some environmental toxins; eliminating pathogenic microorganisms; involvement in the nitrogen, phosphorus and sulfur cycles; and by influencing the solubility and mobility of inorganic ions in soil. Our present knowledge of these microbial reactions is reviewed and used to emphasize significant areas of needed research.

INTRODUCTION

The biological component of the soil has been recognized to be of primary importance to the successful functioning of the "soil filter" during recycling of sewage sludges and effluents. Likewise, under certain situations unwanted biological reactions may occur which are detrimental to the integrity and functioning of the soil filter. This biological component includes bacteria, actinomycetes, fungi, algae, the soil micro- and macrofauna, and higher plants. Since other papers in these proceedings will discuss the contributions of higher plants to waste recycling in soils, this paper focuses primarily on the reactions involving soil microorganisms with a brief discussion of some potentially significant reactions involving the soil macrofauna.

The biological component of soil makes significant contributions to waste recycling in five main areas: 1) decomposition of organic compounds contained in sludge and waste effluents, 2) detoxication of some potentially problematic organic materials contained in sludges and effluents e.g., detergent residues, pesticides, and petroleum hydrocarbons etc., 3) elimination of pathogenic microorganisms, 4) participation in the cycling of nitrogen, phosphorus, and sulfur, and 5) in the reactions which influence the solubility and mobility of inorganic ions.

This paper will present as concisely as possible our present understanding of these microbial reactions, while identifying those areas which are less well understood and which require further research.

Nature of Soil Biological Component

Soil microorganisms in the plow layer of agricultural soils often reach high numerical populations. Estimates of 10^7 bacteria, 10^6 actinomycetes, and 10^5 fungi per gram of soil are typical values obtained by plate counts on various artifical media. Direct microscopic counts for soil bacteria are usually higher with 10^9 cells per gram of soil a common figure. Bacterial populations in the plant rhizosphere are commonly 10 to 100 times greater than the normal soil population with smaller population increases noted for actinomycetes, fungi, and algae. Soil fungi become the dominant numerical group of soil microorganisms in the litter layer (A_0) and (A) horizons of acidic forest profiles. In both agricultural and forest soils the microbial population is concentrated primarily in the surface 15 cm organic matter rich region of the soil and numbers decrease rapidly with depth.

Algae are common to all soils and are most abundant at or near the soil surface. Population estimates usually range between 10^4 to 10^5 per gram of soil[11].

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Biologists in the United States have usually discounted the significance of algae in normal soils and have considered them of economic significance only in fields of paddy rice or in desert algal crusts. In both instances the primary benefit is ascribed to denitrogen fixation by some species of blue-green algae. Some biologists, especially in the Soviet Union, consider that soil algae make other important contributions by producing plant growth stimulants and by providing a significant source of soil organic matter[13]. Regardless of the previous literature, it seems important that the significance of soil algae be re-evaluated under systems of effluent irrigation. Here high soil moisture, high humidity, and high nutrient levels may provide an environment conducive to the development of large algal populations.

Our understanding of soil protozoa is even more fragmentary than that for soil algae. An excellent review of these soil microanimals is provided by Stout and Heal[47]. Populations of 10^3 to 10^5 per gram of wet soil are commonly recorded for temperate soils of moderate fertility. The primary function of protozoa is thought to be that of predation of soil bacteria, e.g., the rapid disappearance of coliform bacteria in soil may result from predation by soil protozoa. In addition, soil protozoa may also affect organic matter cycling of soils by their predation and digestion of soil bacteria. Vegetative cells of soil protozoa normally are found in water films and water filled soil pores. Thus soil protozoa could become of greater importance in soils being irrigated with secondary effluent.

Soil macroanimals are a diverse groups of organisms which include nematodes, earthworms, flatworms, slugs, snails, centipedes, millipedes, woodlice, arachnids and larval, adult and nymph stages of insects. For a series of detailed reviews on some of the more significant groups of soil animals see Burges and Row[10]. Because of the diversity and complexity of this broad group of soil organisms only general comments on their significance in waste recycling seem appropriate. As a group soil animals have also been largely ignored by biologists in the United States, with the possible exception of earthworms. It is this author's opinion that soil macroanimals may be of considerable significance in soils which are being used for waste recycling. Primary functions included the digestion of organic materials, the mixing of surface applied residues and sludges with the soil, and changes in soil aeration and water infiltration. In the latter cases, insect or earthworm burrows might provide a means for effluent to move into and through soil rapidly without adequate renovation.

Numerous estimates of bacterial biomass have been calculated. The data as summarized by Miller[39] show a mean value of bacterial biomass to be 300 g/m² (2800 lb/acre). In most arable soils, the amount of bacterial biomass is commonly estimated to be somewhat less than that of fungi, but to exceed that of the algae, protozoa, and nematodes combined[12]. Estimates of the biomass of actinomycetes is not readily available but is generally considered to be equal to that of the true bacteria. Jenkinson[27] estimated that the soil biomass contained 2.3-3.5 percent of the soil carbon.

Application of sewage sludge or other high organic wastes to soils increases soil microbial numbers[22,40]. Representative data for changes in the population of bacteria and actinomycetes and soil fungi during the decomposition of an anaerobically digested sewage sludge is shown in Figures 1 and 2. Numbers of bacteria and actinomycetes were generally directly related to the sludge loading rate (Figure 1). Within a treatment maximum numbers were usually found after one month incubation and decreased after three and six month incubation. The fungal population also increased in response to the quantity of sludge but the increase was not as pronounced as with bacteria and actinomycetes (Figure 2). This same increase in the fungal population was not evident in the Paulding clay incubated under saturated conditions. Neither did the number of fungi decrease substantially with increasing time of incubation as was true for the bacteria and actinomycetes. This probably represents a profuse development of heavily sporulating species during the initial period of incubation with these spores remaining viable through the three and six month incubation period.

Limited data is available on population changes induced by irrigation with secondary effluent. Unpublished data by Goodfellow from the Pennsylvania State University effluent disposal studies have shown a slight increase (less than 1 log) in the number of aerobic heterotrophic bacteria in the surface one to two inches of soil. These increases were related to the quantity of effluent applied. Small population increases might be expected because of the low organic loading associated with most secondary effluents. Microbial populations may increase in soils used for effluent recycling where perennial forages add appreciable quantities of roots, stubble and rhizomes annually. The changes which might occur in the microbial population of forest soils to which effluent is applied remains an unanswered question, but would probably be more dramatic than in agricultural soils. For example, populations of fungi and some soil animals which often dominate forest soils and litter may decrease in significance under conditions of intermittent soil saturation and high humidity.

Few studies have attempted to evaluate qualitative changes in the microbial population when sewage sludges and effluents are applied to soils. Miller[40]

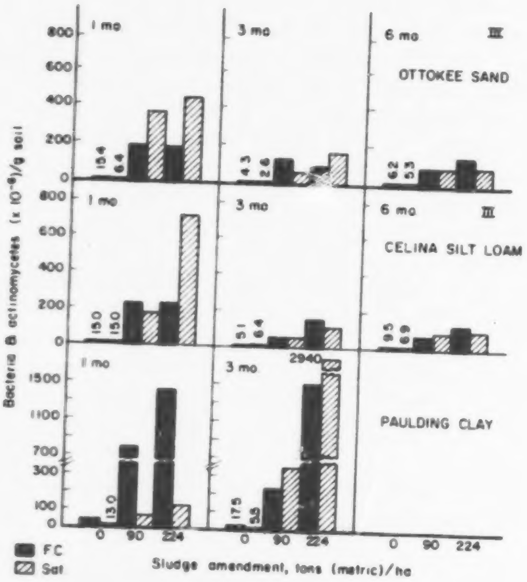

Figure 1: Plate Count of Bacteria and Actinomycetes In Three Soils After Incubation with Anaerobically Digested Sewage Sludge for One, Three and Six Months. (The Temperature of Incubation Was Equivalent to Spring-Summer Temperatures In Columbus, Ohio[40].)

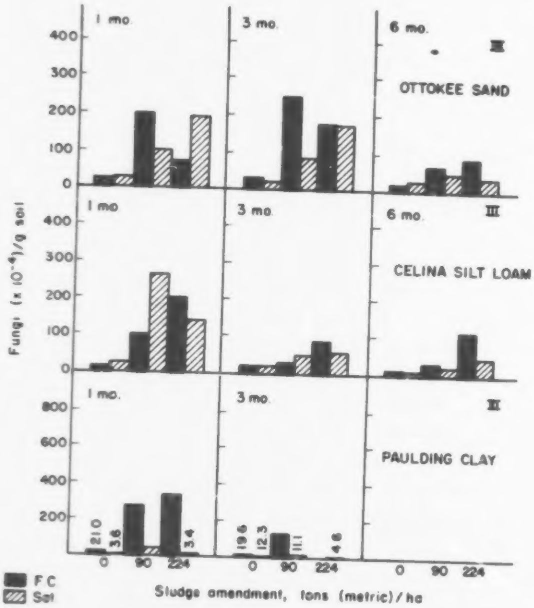

Figure 2: Plate Count of Fungi In Three Soils After Incubation with Anaerobically Digested Sewage Sludge for One, Three and Six Months. (The Temperature of Incubation Was Equivalent to Spring-Summer Temperatures in Columbus, Ohio[40].)

characterized 354 bacterial isolates from two soils amended with an anaerobically digested sewage sludge. The data in Figures 3, 4 and 5 is from this study. Among the more significant findings of this study was the change in the bacterial population from one dominated by gram positive bacteria in the unamended soil to one where gram negative bacteria made up more than 50 percent or greater of the isolates from sludge amended soils. Accompanying this change in gram reaction was a reduction in the number of spore farmers, a decrease in average cell size,

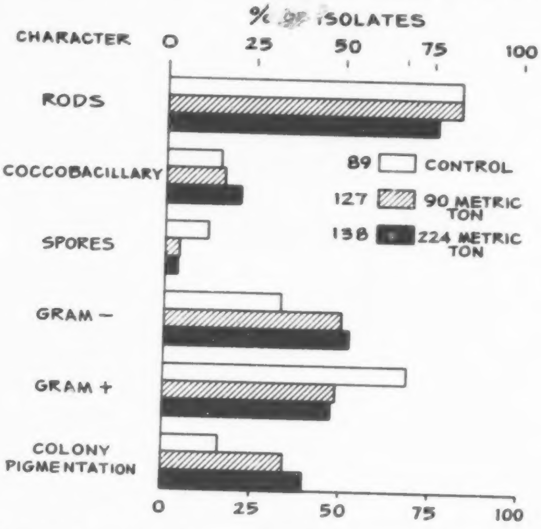

Figure 3: Selected Morphological and Cultural Characteristics of Bacterial Isolates from Sludge Amended Soils. The Isolations Were Made After One Months Incubation with an Anaerobically Digested Sewage Sludge. The Numbers to the Left of the Key Indicate the Number of Isolates Characterized[40].

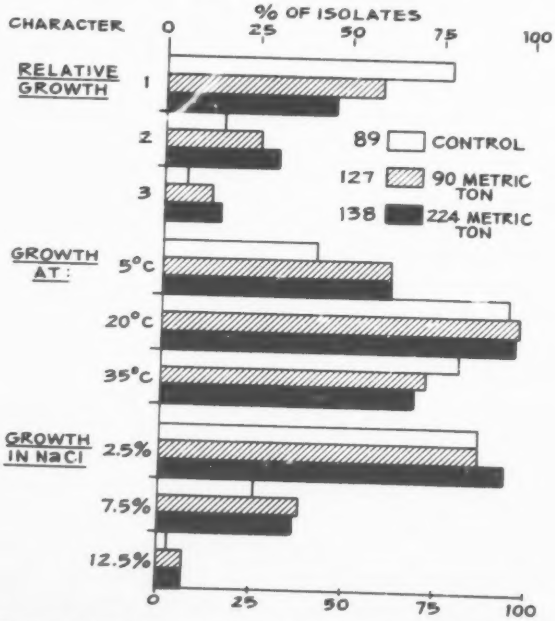

Figure 4: Selected Growth Characteristics of Bacterial Isolates from Sludge Amended Soils. The Isolations Were Made After One Months Incubation with an Anaerobically Digested Sewage Sludge[40].

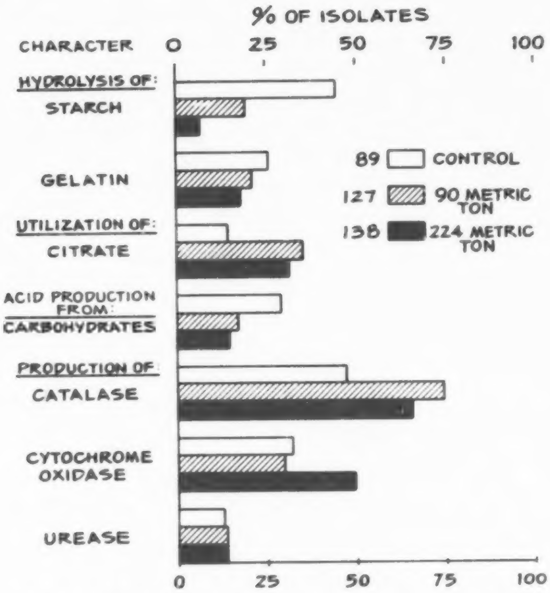

Figure 5: Selected Biochemical and Enzymatic Activity of Bacterial Isolates from Sludge Amended Soils. The Isolations Were Made After One Months Incubation[40].

and an increase in colony pigmentation among the isolates from sludge amended soils. Bacterial isolates from sludge amended soils also differed physiologically from the normal soil bacterial population. Isolates from sludge amended soils generally grew at a faster relative growth rate, grew better at 5°C but less well at 35°C, and tolerated a higher concentration of NaCl. Biochemically the isolates from sludge amended soils had increased catalase and cytochrome oxidase activity, were better able to utilize citrate, but were less able to hydrolyze starch or produce acid from a series of carbohydrates. Lastly, the isolates from sludge amended soils showed a general increase in resistance to antibiotics. These data provide information that the soil microbial population does change (perhaps expectedly) in response to the addition of waste materials. Although these types of studies are of academic interest, it is doubtful if they will provide any information which will help us in better managing soils to which wastes have been added.

CONCLUSIONS

Quantitative and qualitative studies of microbial populations presently add little knowledge directly applicable to managing waste amended soils. Greater emphasis should be given to evaluating any changes which might occur in significant microbial transformations and functions in sludge and effluent amended soils. Particular emphasis should be given to the plant rhizosphere, and to forest soils where effluent applications may have their greatest effects.

Considerable research emphasis should be given to studies on the changes in earthworm population and that of other significant soil animals after sewage sludge and waste effluents have been applied to soils. For example, earthworms have been shown to accumulate heavy metals in sludge amended soils[7], could be important in waste comminution in certain methods of sludge application, and could alter water infiltration to the detriment of soil renovating capabilities.

Lastly, soil algae could become a highly significant component of the soil microbial population with effluent irrigation. Their contribution to dinitrogen fixation and organic matter accumulation may have to be evaluated.

Decomposition of Organic Compounds of Sewage Sludges and Effluents

One primary function of the biological component of the soil is the degradation of the organic compounds of sewage sludges and effluents.

Anaerobically digested sewage sludges contain about 25 percent organic carbon on a dry weight basis[8]. During the process of anaerobic digestion the waste organic solids are stabilized by the almost complete microbial fermentation of carbohydrates (the exception is cellulose) resulting in a 60-75 percent reduction in volatile solids. The residual organic material consists of a mixture of microbial tissue, lignin, cellulose, lipids, organic nitrogen compounds, and humic like materials. The organic carbon content of undigested primary sludge, aerobically, digested, and activated sludges are highly variable but generally higher than anaerobically digested sludge. The chemical analysis of the primary and activated sludges will be similar to microbial cells which dominate these materials. This author had no knowledge of a detailed chemical analysis of an aerobically digested sludge.

Secondary effluent from properly operating activated sludge plants, trickling filters, or lagoons contains relatively low levels of organic compounds. A typical secondary effluent was considered to have a BOD of 25 mg/ l and a COD of 70 mg/ l[15]. Limited information is presently available on the chemical analysis of the organic compounds of secondary effluent[42,44,26]. A portion of the organic materials measurable by BOD are derived from sludge particles carried over from the treatment system, and would have a chemical composition similar to that of microbial tissue. Part of the BOD of secondary effluent is also in the colloidal and soluble states and would have a chemical analysis similar to that of the particulate materials.

The less readily decomposable organic compounds of secondary effluent (refractory organics) are estimated by the difference between the values for COD and BOD. These organic compounds are those which are considered more slowly degradeable e.g., phenols, detergents, fats and waxes, hydrocarbons, cellulose, lignin, tannin, plant and bile pigments, pesticides, and humic compounds.

As might be surmised from a consideration of their variable chemical properties, waste organic compounds will decompose at varying rates. Thus anaerobically digested sewage sludge is not degraded rapidly in soil[5,40]. A maximum of only 17-20 percent of the carbon from anaerobically digested sludge amendments of 90 and 224 metric ton/ ha was evolved as CO_2 during a six month period at soil temperatures equivalent to spring-summer or summer-autumn in Columbus, Ohio (Figure 6). The difference in slope with time shows that the more readily available substrates were decomposed during the initial month (10-13 percent of the carbon evolved) with markedly reduced CO_2 evolution during subsequent months. These data certainly suggest that the addition of anaerobically digested sewage sludge to soils will result in an accumulation of organic matter in soils. Another significant result from the study was the observation that at the rather high rates of sewage sludge loadings employed, the rate of which the carbon was evolved as CO_2 by microbial activity was largely independent of soil properties.

Undigested primary sludge or activated sludge will contain organic residues which are more readily degradable. Data from the ARS, USDA Progress Report[5] report that raw sludges showed an average loss of 27 percent carbon after 54 days incubation in contrast to less than ten percent loss of carbon from digested sludge.

Limited data is currently available on the rate at which the organic compounds of waste water effluents are decomposed in soil. Thomas and Bendixen[48] studied the rate of degradation of septic tank effluent in sand lysimeters and secondary effluent in lysimeters of sand and a silt loam soil. About 80 percent of the organic carbon from septic tank effluent was decomposed during 82-425 day closing cycles with little difference due to duration of closing, temperature or loading rates. Only 68 percent of the organics of secondary effluent was degraded in the sand lysimeters during 513 and 760 day dosing periods while 89 percent was degraded during a 513 day dosing of a single lysimeter containing a silt loam soil. These data would at least suggest that the organic compounds of secondary effluent are readily decomposable and would not by themselves result in the accumulation of soil organic matter. However, many of the soil management systems proposed for recycling and renovating effluents (especially in the humid, high rainfall areas of northeastern United States) utilize forage grasses extensively. Reed Cannarygrass is an example of grass commonly mentioned as desirable for effluent disposal sites. Stubble root and rhizome accumulation may result in a net increase in soil organic matter.

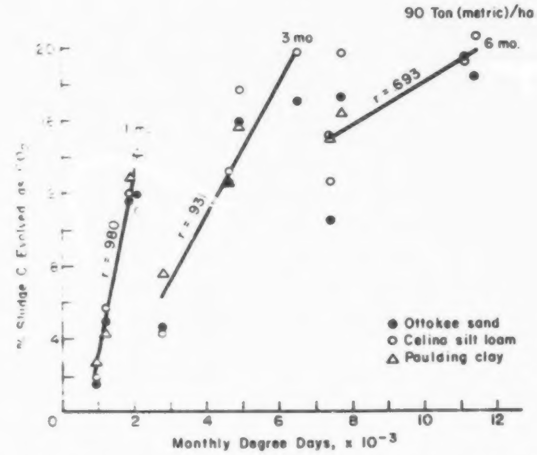

Figure 6: Decomposition of Anaerobically Digested Sewage Sludge In Soil with Time as Influenced by Temperature. Data Points for Each Incubation Time Were Calculated from Measurements of CO_2 -C Evolution from Three Soils Amended with 90 Metric Ton of Sludge/ Ha. Degree Days =

$$\sum_{i=1}^{N}\left(\frac{\overline{X}_{MT}+\overline{X}_{mt}}{2}\right)\times 30.$$

Where X_{MT} = Mean Daily Mas. Temp. During a Month (°F); X_{mt} = Mean Daily Min. Temp. During a Month (°F); N- No. of Months.

CONCLUSIONS

Recycling sewage sludges on land will present different management problems from those associated with effluent recycling. As noted previously, applications of anaerobically digested sewage at the rates presently being recommended for soils will result in a net accumulation of soil organic matter. Organic matter in soils is normally considered a valuable resource; because of its influence on soil structure, water holding capacity, water permeability, cation exchange capacity, and adsorption of heavy metals. However, frequent large applications of sewage sludge or single massive applications could result in an accumulation of organic matter which would adversely affect ion solubility and availability, plant growth, or environmental quality. For example, experiences at the Paris and Berlin sewage farms has indicated that organic matter accumulation was associated with "exhausted soils"[45]. The primary reason cited for the poorer plant growth was an accumulation of Cu and Zn by the soil organic matter in a form available and toxic to the plants. Excessive accumulation of sludge organic matter might adversely affect the soil atmosphere, with the associated problems of odor, reduced root development, and increased mobility of many heavy metals. It seems important, therefore, that further information be obtained on what the desirable level or organic matter accumulation might be for a given management system e.g., strip-mine spoil reclamation vs. agricultural use.

Adequate management of soils to which sewage sludges are being added requires further information on the rate of sewage sludge decomposition which might be expected with different methods of sludge application or different loading rates and frequencies. Thus the rate of sludge decomposition might vary considerably when applied by surface irrigation, soil incorporation, deep plowing, injection, etc. Likewise the expected rate of sludge decomposition will differ when applied in a single massive application versus repeated smaller additions.

One other consideration in managing sludge disposal sites is a concern for possible problems which might arise when these sites are abandoned, whatever the reason for abandonment might be. During the period of regular sludge application these soils will have reached a new higher equilibrium level with respect to organic matter. When further additions are halted, the organic matter will begin to decrease to a new organic matter level characteristic of the soil, climate, and soil management practices. What significance this new organic matter level will have on heavy metal toxicity and movement, nitrogen transformations, and other properties influencing plant growth must remain speculative.

One last consideration will be a suggestion that some parameters other than BOD or COD be used to define the organic matter content and decomposability of liquid wastes in soils. These tests were designed for use in evaluating the environmental impact of waste discharge into streams and lakes, and have proven useful and meaningful in designing sewage treatment systems. Their applicability as a meaningful term in recycling and disposing of organic wastes in soils is questionable.

Elimination of Environmental Toxins

Municipal waste effluents and sewage sludges contain varying concentrations of a variety of organic and inorganic substances which are considered potential environmental toxins. Among the compounds frequently found are phenolic compounds, the chlorinated hydrocarbon pesticides and chlorinated biphenyls, detergent residues like ABS and NTA, petroleum products, heavy metals, etc. The concentration of any one of these compounds which would reach the soil during waste recycling would depend primarily upon the industries utilizing the sanitary system, the degree of industrial pre-treatment, and the efficiency and type of municipal waste treatment facility. Normally the concentration of any one of these compounds reaching the soil will be low.

The groups of organic compounds listed above are chemically diverse and few generalizations on microbial degradation or detoxication in soil can be made[39]. For a more detailed treatment of microbial-metabolism of many of these compounds the readers are referred to the following papers: phenols[16,21,24], herbicides[23,28], insecticides[34], fungicides and nematocides[49], hydrocarbons[19,37], and detergent residues[6,25].

CONCLUSIONS

Under normal circumstances the potential environmental toxins which will reach the soil in waste effluents and sludges should not cause environmental problems. This conclusion was derived from consideration of the initially small concentrations normally present in these waste materials and by the ability of the soil microbial population to metabolize or detoxify a large number of them. In the latter case it is important that physical and chemical adsorption on soil particles provide sufficient retention time for microbial activity to proceed.

What does seem important is that each community or sanitary district contemplating waste recycling on land be aware of these potential hazards and adequately characterize their waste materials with respect to them. If the risk is severe, steps should be taken to remove the toxin prior to land treatment. If the risk is moderate, adequate monitoring of the persistence, mobility or environmental effects of this compound must be provided. It is also imperative that our industries, responsible government agencies, and our scientific community continually evaluate potentially harmful synthetic or natural chemicals so that steps can be taken to eliminate them from use if proven harmful.

Research in this area should continue to focus on the structural basis for resistance to microbial decomposition of a variety of synthetic organic compounds. Emphasis should also continue on understanding the metabolic schemes by which compounds presently reaching our soil environment are metabolized by the soil microflora.

Elimination of Pathogenic Microorganisms

Recycling of sewage, primary and secondary effluents or liquid sewage sludges on land may present a potential health hazard because of the human and animal pathogens which these wastes contain. Among the common pathogens found in these waste materials are the bacterial pathogens *Salmonella, Shizella, Mycobacterium,* and *Vibro comma;* the hepatitis viruses, enteroviruses and adenoviruses; and the protozoan, *Endomoeba histolytica*[20]. Cooke and Kabler[11] have also shown the several fungi capable of causing diseases in man are present in sewage and sewage polluted water. Cook[12] found human pathogenic fungi and fungal allergens in sewage sludges and sludge amended soils.

Since all large scale proposals for land application of secondary effluents include plans for prior disinfection of effluent, the concern for survival of pathogens in soil would seem unfounded. Likewise, most smaller municipalities would also be required by state regulations to provide adequate disinfection for effluents being applied to land. Yet for two reasons the health hazards associated with land disposal of waste effluents still remains a valid concern. First, methods of disinfection are not uniformly effective against all potential wastewater pathogens. Viruses in particular may survive usual chlorination procedures[15,17]. Second, effective day to day disinfection of effluents may be limited by human and mechanical failure. No documentation of this latter point is presently available.

Sewage sludges provide a slightly different problem. Anaerobic digestion of sludge results in a significant reduction in numbers of pathogenic microorganisms, but does not result in complete elimination of pathogens[38,41]. In addition, many treatment facilities do not disinfect sludges prior to land application. Regardless of the reason, the uncertainty of knowing whether or not pathogenic microorganisms are still present in sludges being applied to land makes information on the survival in and movement of pathogens through soil a significant concern.

Data from the extensive studies by McGauhey and Krone[36] and Krone[29] have shown that pathogenic microorganisms are largely retained at or near the soil surface and that movement through the profile is not considered a severe problem. Some doubt about the movement of virus particles still remains, however. Once the pathogenic microorganisms are retained the next consideration is the length of survival of these microorganisms in the soil matrix.

Most studies have indicated that pathogenic and indicator bacteria are eliminated from soils rather rapidly. The due back curves of Van Donsel *et al*[50] for fecal coliforms and fecal streptococci as shown in Figure 7 are typical of those commonly but not always obtained. Survival of bacterial pathogens and indicator bacteria in soil for longer time periods have been reported[17,46]. Whether the typical due back curves are descriptive of the die back of pathogenic viruses is still an open question, and one which should be given a high research priority.

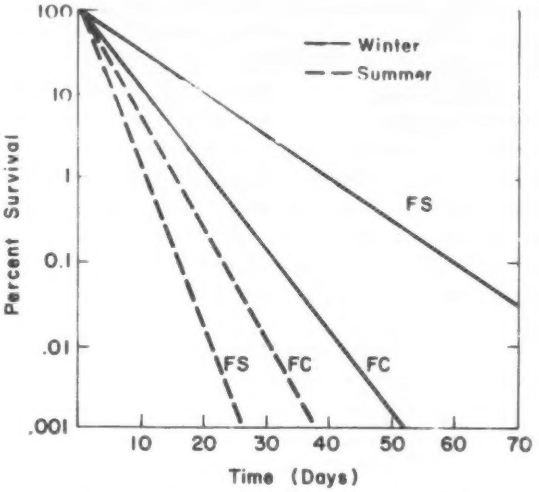

Figure 7: Survival of Fecal Coliforms (FC and Fecal Streptococci (FS) In Soil[50].

Both abiotic as well as biotic factors are considered significant in the elimination of pathogenic and indicator organisms from soil. Abiotic factors of importance are texture, moisture, pH, aeration, temperature and organic matter content. Soil microorganisms could be involved indirectly as a result of microbially mediated changes in soil pH, aeration, and organic matter content. Direct participation of the soil microbial population in the elimination of the "foreign" pathogenic microorganisms would seem to be an example of a "homeostatic" reaction of the soil microbial community which maintains the constancy of the community[3]. The mechanism involved in the elimination of the pathogen may involve one or all of the following: production of microbial toxins; enzymatic lysis; predatory protozoa; parasitic bacteria, fungi, and phage; and the inability of the aliens to compete effectively with the indigenous microbial community for nutrients.

CONCLUSIONS

Some pathogenic microorganisms will undoubtedly reach the soil and vegetation during recycling of effluents and sewage. However, since considerable literature indicates limited transfer of microbial cells through the soil profile and a reasonably rapid die back of the pathogens in the soil matrix, the presence of pathogenic microorganisms should not be a factor limiting the applicability of recycling wastes on land.

This does not mean that reasonable caution should not be employed to limit aerosol formation during irrigation of waste effluents, that the general recommendation that waste materials not be applied to crops which will be consumed raw be rescinded, or that the runoff from fields used for recycling not be controlled. All municipalities or sanitary districts employing land for recycling of wastes should also be prepared to adequately monitor the soils and ground for the survival of pathogens.

It is also imperative that strong research priority be given to studies on the movement and survival of pathogenic viruses in soils. These studies should include field studies which evaluate survival under different conditions of management for effluent and sludge disposal sites. It would be hoped that some method could be developed that would allow realistic monitoring of soils and groundwater supplies for pathogenic viruses.

Continuing efforts should be made to improve our understanding of the biotic and abiotic factors affecting the survival of pathogenic microorganisms in soils. Methodology should be evaluated and improved for the monitoring of soil and groundwater contamination by pathogenic bacteria or fungi.

Microbial Reactions Which Influence the Mobility and Plant Availability of Ions In Soil

Of the concerns which might limit the recycling of effluents and sludges on land, those involving the accumulation and movement of N, P, and various inorganic ions are potentially the most serious. The soil microbial population is directly or indirectly involved in the soil reactions of most of these elements, and greatly influences the success of waste recycling on land.

Nitrogen

The microbial reactions involving nitrogen which are of primary significance to waste recycling are mineralization, nitrification and denitrification.

Secondary effluent contains rather modest concentrations of both NH_4^+- N (9.8 mg/ l) and NO_3^-- N (8.2 mg/ l) with a small amount of organic N (2.0 mg/ l). The values given are typical values[15] and may differ considerably depending upon the efficiency and retention time of the treatment system. The application of large amounts of secondary effluent to soils, (up to 120 inches/ acre/ year as proposed in some engineering feasibility studies) would however, result in rather large annual applications of nitrogen.

The carbon:nitrogen ration (C:N) of secondary effluent will be less than 10:1 so net mineralization of the small amount of organic nitrogen will occur. This mineralized nitrogen as well as the NH_4^+- N initially present in the effluent should be readily nitrified by the chemosynthetic autotrophs *Nitrosomonas* and *Nitrobacter*. The exceptions will be during winter months in regions of low winter temperatures, in acid forest soils or other soils with a low pH. It is also a possibility that nitrification could be inhibited in effluent recycling systems employing forage grasses. An inhibition of nitrification in grassland soils has been frequently reported in the literature[14].

The adsorption and utilization of this NO_3^- by an actively growing agronomic crop or by forest vegetation is extremely important for the success of effluent recycling systems. Excess NO_3^- above that required by the growing plants will be subject to leaching and could result in groundwater contamination. For this reason rates of effluent application must be based on the nitrogen needs of the vegetation taking into account that nitrogen which will be released by mineralization of soil organic matter and any remaining plant residues and the potential loss of NO_3^- through biological denitrification.

The significance of biological denitrification during application of secondary effluent is difficult to evaluate. Estimates of nitrogen losses through biological denitrification based on greenhouse and lysimeter studies have averaged 15 percent[4]. High moisture conditions and intermittent soil saturation would favor oxygen depletion and increased denitrification if a readily available source of decomposable organic matter is present. Although the effluent itself would probably not supply sufficient organic matter, decomposing crop residues or plant root exudates might be adequate. As mentioned in the previous paragraph, nitrification might be inhibited in the rhizosphere of forage grasses. Since NO_3^- is the starting point for biological denitrification such an inhibition would restrict nitrogen losses through denitrification. Because of some of these unanswered questions studies of biological denitrification under field conditions is a primary research priority.

Anaerobically digested sewage sludge contains an average of 2.4 percent nitrogen and activated sludge averages 5.6 percent nitrogen, half of which is in the ammonium form[8]. This quantity of nitrogen would make both sludges low analysis fertilizers with respect to nitrogen. However, the application of very large quantities of sludge as often recommended for sludge disposal on land (up to 100 tons/ acre) will result in extremely large additions of nitrogen. Limited attempts have been made to estimate the mineralization of organic nitrogen of anaerobically digested sludge. Larson *et al*[31] utilized relative plant response to estimate a six percent annual mineralization. Miller[40] estimated that from 3.3 to 3.4 percent of the sludge organic nitrogen appeared in the displaced soil solution of a sandy soil after six months incubation.

Nitrification of the added ammonium nitrogen or mineralized organic nitrogen may be rapid or proceed only after a lag phase. Premi and Cornfield[43] found that sludge amendments which supplied greater than 102 lbs of NH_4^+- N per acre inhibited nitrification for up to eight weeks. The inhibition was thought to be caused by an organic toxin. Miller[40] found that nitrification was inhibited for one month to two months in sand and silt loam soils amended with 40 and 100 tons per acre of an anaerobically digested sewage sludge. After this lag period nitrification was rapid and extensive.

Large additions of sewage sludge to soils and extensive nitrification of ammonium and mineralized nitrogen could result in nitrate accumulation above that required by the crop. This nitrate would be subject to leaching and could result in deterioration of groundwater quality. Lysimeter studies by Hinesly *et al*[23] have shown the accumulation and movement of NO_3^- through four feet of a silt loam soil amended with from five to ten inches of liquid digested sewage sludge. Nitrate nitrogen found in the leachate was considerably higher than unfertilized check plots or control plots receiving 200 lbs of N per acre as commercial fertilizer. The high risk of NO_3^- leaching has prompted Hinesly *et al*[23] to propose that no more than two inches (~ 6.6 tons/ acre) of an anaerobically digested sewage sludge be added to supply the nitrogen needs of a non-leguminous crop. Even this rate supplies over 600 lbs of N per acre.

Biological or chemical denitrification could effectively reduce the problem of excess nitrate but no definitive studies have been conducted to estimate denitrification in sludge amended soils. High organic carbon wastes such as sewage sludge might provide both the source of available carbon for the denitrifying bacteria as well as an environment conducive to zones of anaerobiosis.

CONCLUSIONS

It should be apparent from the previous discussion that there are many unknowns in our understanding of the important nitrogen reactions associated with managing soils for recycling effluents and sludges. Because of the environmental hazards associated with nitrate leaching it seems advisable to recommend that application rates for both effluent and sewage be based on the amount of mineralized nitrogen removed by the accompanying crop. The obvious problem associated with this decision is that we presently have insufficient data to make good estimates of this value.

Our research needs include estimates of nitrification and denitrification in soils and the rhizosphere of crops being irrigated with secondary effluent; data on the rate of mineralization, nitrification, and denitrification of sewage sludge nitrogen; and information on the rate of and factors which influence NH_3 volatilization during storage and application of sewage sludge to soil. In the latter case any losses of NH_3 would reduce the problem of excess NO_3^-.

Phosphorus. Chemical fixation of orthophosphate by Fe, Al, Ca, and clay minerals in soil and removal by growing plants provide the primary mechanisms for restricting the mobility of phosphorus applied with effluents and sludges. Soil microorganisms influence the effectiveness of the soil for renovation by mineralizing orthophosphorus from the more mobile organic and condensed phosphates so that chemical fixation can occur. The microbial synthesis of organic phosphorus and inorganic poly P in soils from orthophosphorus could result in greater mobility of P through the soil profile. The significance of both of these reactions needs further clarification. Buford and Bremner[9] have not been able to substantiate that claim that phosphine (PH_3) is produced through the microbial reduction of phosphate.

Sulfur. The microbial reaction of primary interest in waste recycling is the oxidation of metal sulfides and H_2S to $SO_4^=$ which is both mobile and available to plants. Organic sulfur of effluent and sludges will be mineralized and oxidized to $SO_4^=$. Saturation of soils during effluent irrigation could result in anaerobic soil conditions and the microbial reduction of $SO_4^=$ to H_2S. However, proper drainage and management should eliminate this problem.

Inorganic Ions. Waste effluents contain relatively low concentrations and sewage sludges high concentrations of metallic and non-metallic cations and anions. The exact composition of inorganic constituents is extremely variable and dependent upon the industrial sources which contribute wastes to the sanitary treatment system as well as the treatment processes themselves. When secondary effluents are applied to soils most of the heavy metals are retained within the surface horizon by interactions with soil organic matter and colloidal clay minerals and by precipitation as insoluble oxides, hydroxides, phosphates, or sulfides. These same reactions will influence the solubility of metal ions of sewage sludges as well, but the large quantities of organic matter present may retain some of the metals in organic combination until released by microbial activity.

The microbial reactions of primary concern to the solubility and mobility of inorganic ions involves one or more of the following: oxidation-reduction, precipitation, solubilization, volatilization, production of low molecular weight organic chelates, and the formation and degradation of soil organic matter capable of forming insoluble chelates. These reactions were discussed in greater detail in a recent paper[40].

For a more thorough discussion of the soil reactions of metal ions and other significant inorganic ions the readers are referred to reviews by Ehrlich[18] and Leeper[32].

CONCLUSIONS

Considerable research emphasis is presently being given to the reactions of heavy metals in soils and their adsorption by plants. This emphasis has arisen from a concern about the impact of heavy metals from a variety of sources on our environment. Renewed interest in recycling of effluents and sludges on land has been one area which has done much to stimulate research on heavy metal ions.

The microbial reactions associated with waste recycling in soils which require continued research emphasis are those involving the adsorption of high concentrations of metal ions by soil organic matter and the solubilization of heavy metals by complexing with low molecular microbial exometabolites. Both reactions are extremely important to our understanding of ion mobility and plant adsorption of metals in soil.

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DISCUSSION

QUESTION: George Ward, George D. Ward & Assoc., Portland, Oregon. I have a question to ask Dr. Miller. I want to confirm a figure that I wrote down, if it is correct on the bacteria biomass estimate. If it was twenty-five hundred pounds per acre, and if it is, I hope it is correct, because I want to take that home. That is about the equivalent of the weight of a brahma bull running around on the ground and we have land out there that will only support one cow per four acres and if we can get one bull on the ground—I am serious. And if this is what he didn't say, what I would like him to help me with, is how deep in the soil is that average bacteria biomass and is that natural soil before we perhaps deployed them and if we can maybe put this in by some deep plowing at some rates I am not sure. But I don't think it would cost too much to plow very deeply in soil and imbed this instead of a centimeter, perhaps even three and four feet. We might get a whole herd of brahma bulls down there.

ANSWER: The figure that I have that is to the best of my estimate is twenty-eight hundred pounds per acre for about the surface fifteen centimeters, and that is what the calculation was. Normally that is where our microbial population is and its activity is there. It decreases very rapidly both in numbers and biomass as you go below that, and of course the organisms are there because the organic matter is there and these are natural systems, whether they be grass land ecosystems or forest ecosystems, etc. Now, the idea of deploying in certain circumstances would probably be substantial except you still had to be concerned about aeration down to that point. The anaerobic system is going to have less cell numbers per unit of carbon metabolized, it is going to metabolize it less readily. If you can keep it aerated with your deep plowing, you are going to increase your organic matter content down to that depth by incorporation. I think there are some problems of deploying in certain soil systems. I know the soils people at Ohio State are very skeptical about deep plowing because it has been proposed as a method of improving infiltration in one of the Corps of Engineer plants in Ohio. We are skeptical because of the swelling properties of some of the clay minerals which basically would seal over the system again, and you are not gaining anything. So, maybe we could put this in the realm of an unknown that might need some looking at some of the ideas.

Inorganic Reactions of Sewage Wastes with Soils

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ABSTRACT

Sewage wastes decompose in soils to CO_2*, water, residual soil organic matter, and inorganic constituents. The more soluble elements, which are generally present as* Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^-, *and* H_3BO_3*, either remain in solution or exchange with ions on exchange sites on soil surfaces. Considerable technology is available on salt problems, ion exchange reactions, and movement of soluble salts through soils that can be applied to the application of sewage wastes to soils.*

Another group of elements, which include Zn, Cd, Pb, Cu, Ni, Cr, Hg, Mn, Co, P, As, Se, and Mo, form compounds and reaction products of intermediate solubility. Under many soil conditions these elements are sufficiently soluble that they are taken up by plants and cycled into the food chain of animals and man. Recent developments in soil chemistry in the areas of mineralogy, chemical equilibria, and metal chelation offer many opportunities for critically and quantitatively studying the solid phase-soil solution equilibria. Such basic studies are needed to predict the long-term fate of potentially toxic heavy metals and other inorganic constituents that are added to soils by the addition of sewage wastes. Eventually these elements will find a new home in the mineral matrix of soils that will govern their availability to plants and their movement in soils.

INTRODUCTION

Soil constitutes a natural and often convenient depository for sewage wastes. When placed in the soil, these materials decompose and undergo various transformations. The organic components are decomposed largely to CO_2, water, and residual soil organic matter. The soluble inorganic constituents are leached away by drainage waters while insoluble products accumulate in the soil to become a part of the soil matrix. The question is asked "Will these inorganic constituents that remain accumulate at sufficient levels that they will present future hazards to man as he attempts to use these soils for various purposes in the future"?

Soils comprise a complex chemical matrix consisting of numerous primary and secondary minerals in various stages of weathering. The clay fraction contains negatively charged colloides capable of adsorbing and exchanging cations. Because of the amorphous nature and a lack of knowledge of many of the solid phases that form in soil, too many scientists consider the chemical reactions in soils solely as adsorption reactions of the added constituents onto soil surfaces. Recent advances in soil chemistry have demonstrated that consideration must be given to the specific ionic species in the soil solution and to many dissolution and precipitation reactions that are involved. The stability of metal complexes, metal chelates, and solid phase precipitates take on new meaning when such considerations are given.

The scope of this paper is to show that the application of basic chemical principles to soils can help eliminate many needless experiments that otherwise will be proposed to solve the problems of sewage waste disposal in soils. Many related aspects of the sewage disposal problem are covered in different reports of this workshop, therefore, this paper is restricted to the chemical interactions of inorganic constituents in soils as they relate to soils as a depository for sewage wastes.

Reactions of Sewage Wastes with Soil

The general nature of the reactions of sewage wastes with soil is depicted graphically in Figure 1. With time, the added wastes are broken down (reaction 1) and the soluble constituents become part of the soil solution. The released cations can exchange with those already on exchange sites in the soil (reactions 2 and 3). When the solubility of levels of ions in solution exceed the solubility of solid phase compounds and minerals, these compounds can precipitate (reaction 4). When the soil solution becomes undersaturated to any solid phase or mineral that is present, that phase can dissolve (reaction 5). Ions in the soil solution can be removed by plants or leached from the soil by water moving through the soil profile (reaction 6). Constituents are also ingested by microorganisms and incorporated into soil organic matter (reactions 7 and 8). Gaseous constituents enter the soil air and may escape from the soil (reaction 10), or components of the soil air may react with those in the soil solution and became part of the soil matrix (reaction 9).

The soil solution is affected by all the reactions that occur as constituents are either added to or taken from it. The composition of the soil solution is ultimately controlled by the solubility of various mineral phases in soil. In many reactions the rates of precipitation and dissolution are sufficiently slow that kinetic as well as thermodynamic factors must be considered.

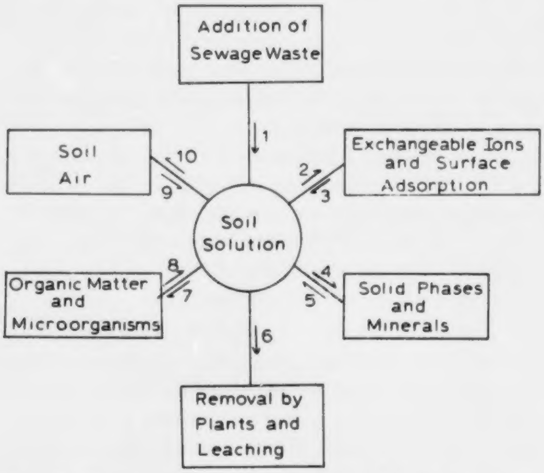
Addition of Sewage Waste
1
Soil Air
10
9
Exchangeable Ions and Surface Adsorption
2
3
Soil Solution
Organic Matter and Microorganisms
8
7
Solid Phases and Minerals
4
5
6
Removal by Plants and Leaching

Figure 1: Diagrammatical Representation of the Reactions of Sewage Wastes with Soil.

Classification of Inorganic Sewage Constituents

Water is the most abundant inorganic constituent in sewage. This compound is ubiquitous in soils and is of little concern from a long-term pollution standpoint.

Water percolates through soils via the normal drainage channels carrying with it soluble salts, mainly Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-. SO_4^{2-}, NO_3^-, $HCO_3^-$and H_3BO_3. These soluble constituents often cause problems. Under low rainfall conditions some of the salts accumulate in the soil causing toxicities to growing plants. The presence of high sodium leads to deflocculation and poor physical properties of soils. Under high rainfall or irrigation the soluble salts may be leached through the soil and pollute the drainage water or underground water supplies. The detrimental effects of soluble salts in sewage wastes can be quite adequately accessed on the basis of past and continuing investigations of salt problems in soils[11]. Avoiding large scale deposition of soluble salts in sewage systems may be desirable under certain circumstances.

The major exchangeable cations in soils comprise Ca^{2+}, Mg^{2+}, Na^+, K^+, and acid soils also include Al^{3+} and H^+. Actually any cation added to the soil is capable of exchanging with cations on the exchange. The controlling factor governing the quantity of ions on the exchange is the activity of those ions in solution. Many metal cations present in sewage wastes form precipitates and solid phases that limit their concentration in the soil solution. Thus, only a small fraction of those ions will remain on the exchange. The less soluble cations will occupy the exchange only until the precipitation reactions occur and reduce the ionic activities in solution. These precipitation reactions may continue for several weeks, and in some cases for several years where heavy and continued applications of sewage wastes have been made. We must consider the solid phases that form in order to understand the chemical transformations that occur and the resulting equilibrium relationships.

Another group of the inorganic elements of concern in sewage wastes form compounds of intermediate solubility. These include: Zn, Cd, Pb, Cu, Ni, Cr, Hg, Mn, Co, P, As, Se and Mo. Considerable attention has been given to many of these elements and the reactions they undergo in soils[1,2,3,10,12]. Much of this work, however, has been empirical and very few basic chemical studies have been made to critically examine the precipitation reactions that take place in soils and how solubility is affected by specific parameters. The reaction products of these elements are of concern because they remain sufficiently soluble under various soil conditions that they are taken up by plants and cycled into the food chain of animals and man.

Another classification of inorganic constituents are those that form relatively inert reaction products in soils. These include cations of the higher oxidation state such as Fe^{3+} and Mn^{4+}. As long as soils are well oxidized these elements remain precipitated as highly insoluble oxides. These elements, however, cannot be considered permanently insoluble in soils, because under reducing conditions they may become soluble and mobile. It is not enough to consider an element by itself. Its oxidation state, and complexation with other ions and chelating agents determines whether a given element will be classified in one catagory or another. The intermediate valence state of Cr^{3+} is stable in most soils and precipitates as insoluble oxides.

The Form and Fate of Inorganic Elements In Soils

Nitrogen

Nitrogen is a significant component in most sewage waste and often limits the loading rates of sewage wastes on cultivated lands by the amount of nitrogen a crop can tolerate. Decomposition of organic residues releases NH^{4+} that is soon oxidized NO_3^-. Nitrate normally remains in solution as an anion and moves with the soil solution. Under reducing conditions NO_3^- can be reduced to NO_2^- (nitrate) and to N_2 (nitrogen gas) and N_2O (nitrous oxide). These gases may escape to the atmosphere and constitute denitrification losses from the soil. Under extremely reducing conditions these forms of nitrogen can also be transformed into NH^{4+} which behaves similarly to K^+ in the soil. As oxidizing conditions return, however, NH^{4+} will again oxidize to NO_3^-.

Nitrogen may present several short range problems: too much sewage waste releases N that injures crops and pollutes the groundwater. Nitrogen from sewage wastes is not expected to produce any long-term hazards in soils because it will not remain there permanently. The slow release of N from the residual organic matter can be considered a beneficial factor in soil fertility.

Phosphates

Phosphates are an important component in most sewage wastes, since P forms relatively insoluble reaction products in soils. In acid soils Al and Fe phosphates are precipitated, while in soils of higher pH Ca phosphates predominate[8]. These reaction products are sufficiently insoluble that P is held in the upper few centimeters of most soils and very little P moves into the drainage water. High levels of P can sometimes cause nutrient imbalances such as P induced Zn, Fe, Mn, and Mo deficiencies[9]. The capacity of soils to react with phosphates is almost infinite because of the large quantities of Fe, Al and Ca that are present as potential reactants.

Polyphosphates have been used in detergents. The polyphosphates can also precipitate, but in some cases remain temporarily soluble. The formation of insoluble $Ca_2 P_2 O_7 2H_2 O$ lowers the soluble phosphorus level to about 10^{-9} molar. With time, the polyphosphates will hydrolize in soils and be transformed into the orthophosphates.

Additions of rather large quantities of P to soils as may be done with large additions of sewage sludge may lead to serious short-term problems. These include over fertilization with P, induced deficiencies, and transport of P to drainage waters. Such additions should, however, produce few long-term problems in soils because of the tremendous capacity of soils to supply Fe, Al, and Ca with which to react. The addition of sewage waste should be beneficial in supplying a ready source of available phosphorus as this is one of the major nutrient deficiencies throughout the world.

Calcium, Magnesium, Potassium and Sodium

These cations are involved in the exchange reactions in soils, and to the extent that they can be retained by exchange sites, they will be slowed down in their passage through the soil. Eventually with continued leaching some of these cations will enter the drainage water. Since these ions are abundantly present under natural soil conditions, they are not expected to constitute great hazards. As mentioned earlier, if large quantities of Na are added, it of course can lead to saline and sodium-affected soils. Some of these cations will also be incorporated in secondary clay minerals and calcium carbonate. Again, these are normal soil forming processes and would seem to constitute no serious long-term pollution problems in soils.

Zinc, Cadmium, Copper and Nickel

These divalent metal ions are normally not found in soils in large quantities. Therefore, their inclusion in sewage wastes may increase the total content of these elements in soils significantly. Although these cations can be held as exchangeable ions, only small quantities will remain on the exchange as precipitation reactions lower their level in solution below that of the common exchangeable cations. The exact reaction products that precipitate in soils with these cations are not known, but likely involve substitution in crystalline minerals and amorphous precipitates, as well as forming possible discrete silicate compounds. The activities of these metal cations are expected to decrease with increase in soil pH. Recent studies[4,5] indeed indicate that this happens. For zinc and copper there is an approximate 100-fold decrease in activity for each unit increase in soil pH. More attention should be given to these metal cations and the long range chemical reactions they undergo in soils. These metals are potentially toxic to animals and plants and may constitute future hazards if they are continually added to soils. To the extent that these elements form silicate minerals, it should be recognized that the abundance of silica could provide the reactant to immobilize rather large quantities of these metals with time. Further investigations of the reactions of these metal ions in soils should be thoroughly investigated in order to predict the long-term fate of these metals in soil environments and their incorporation into secondary minerals.

Iron and Manganese

These two metals are characterized in well-oxidized soils as forming highly insoluble oxides and hydroxides. The solubility of these hydroxides limit the chemical activity of these metal ions to very low levels. At low pH and under reducing conditions, however, these metals can be solubilized and become mobile in the soil as Fe^{2+} and Mn^{2+}. Considerable work has been done on concretions of iron and manganese at the boundary lines where reducing oxidizing conditions change. Such conditions are responsible for the formation of Fe and Mn pans, concretions and deposits that often plug tile drains. Iron and Mn are abundantly present in natural soils, so the addition of these elements in sewage wastes are not expected to cause any unusual problems. Recent investigations[4] have given detailed chemical information on the ionic species of Fe and Mn in the soil solution and the effect of redox equilibria on these relationships. Further studies are necessary in order to pinpoint the redox conditions in soils that affect the solubility relationships of Mn as it becomes toxic under low pH conditions.

Chromium

Chromium is generally not, but can be, a significant component in sewage wastes, especially from certain industrial areas. In soils, however, Cr is generally oxidized or reduced to Cr^{3+} and precipitated as an insoluble hydroxide. Further investigations should be made under adverse conditions such as low pH and changing redox potentials to access potential hazards.

Lead

Considerable attention has been given to lead as an environmental contaminant because of its wide use as an additive for gasoline. Lead forms relatively insoluble compounds in soils. Only recently has attention been given to the solubility relationships of $PbSO_4$, $Pb_3(PO_4)_2$ and $PbCO_3$ as possible controlling mechanisms in various soils[4]. These relationships need further testing in order to clarify the mechanism of lead reaction and fixation in soils. It would appear that soils have a rather large capacity to immobilize Pb. The long term accumulative effects of lead in soils are uncertain at this point, but certainly need more consideration. If $PbCO_3$ is involved as a reaction product, there is the possibility that soils of high pH, upon becoming acidic, could release Pb at some future time.

Mercury

Mercury forms insoluble compounds in the soil, lowering the activity in solution such that very little movement occurs and very little mercury is removed by plants. The soil would appear to form a good sink for this metal. Since the quantities of mercury added in sewage wastes are relatively small, there appears to be no great concern for this metal at the rates at which it is applied to soils. Under low pH conditions and with reduction, Hg may be mobilized. It can also form soluble complexes that may be involved in its mobility in soils under certain conditions. Further investigations are necessary in order to clarify the detailed soil chemistry of this metal and its complexes under various soil conditions.

Cobalt

Cobalt is somewhat similar to Ni in its chemical reactions in soil. Since most sewage wastes contain only small quantities, there has been no widespread concern. As a component of sewage wastes cobalt in soils appears to be strongly associated with Mn oxides. Apparently, this metal cation substitutes for Mn^{2+} and is largely associated with Mn in soil. Most of the problems with Co have been deficiencies in grazing animals as Co is essential to ruminants. At the present level of cobalt in most sewage waste there appears to be little long term concern with this element.

Molybdenum

The Mo content of sewage wastes is rather small. However, consideration should be given to this metal. It is present in well-aerated soils as the MoO_4^{2-}. This anion reacts with Fe^{3+} to form ferrimolybdate. This compound is extremely insoluble under acid conditions, but its solubility increases 100-fold for each unit increase in pH[4,5]. In soils below 7, Mo excesses are not expected to occur. Unlike P, Ca molybdates are highly soluble and provide no limit on the solubility of Mo at high pH. Thus, in calcareous soils the solubility of Mo is sufficiently available to plants as to induce molybdenosis or Cu deficiency in grazing animals. The problem of molybdenosis further made worse by poor drainage and reducing conditions in soils. Investigations are underway to determine possible limits of Mo in soils and water in order to avoid molybdenosis in animals.

Selenium and Arsenic

The solubility relationships of Se in soils has been studied[13]. Ferric selenites appear to be some of the more probable reaction products. The solubility of $SeO_3{}^{2+}$ is expected to increase with pH and to be affected by changing redox potentials. Little is known about the chemistry of As in soils. Further examination of these relationships are needed.

Chelation of Metal Ions In Soils

Most metal ions form soluble complexes and chelates. These combinations increase the solubility and mobility of metals in soils. Our understanding of the role of metals in soils cannot be understood until these complexes and chelates are given due consideration. Metal ions compete for sites in chelates and the overall chemical equilibrium relationships in soils must be considered before the extent of complexation can be estimates[7,8]. Recent advances in this field point out the importance of metal chelation on metal ion solubility and movement. Further advances in this field will be possible once the solid phase solution equilibrium of the various metal cations can be defined and expressed quantitatively. Without a knowledge of these quantitative relationships the role of metal ions in soils and their mobility and availability to plants will remain as empirical observations on isolated soils. Further advances in this area are possible and should be pursued.

RECOMMENDATIONS

The fate of inorganic constituents that are added to soils in the form of sewage wastes present many intriguing challenges. The interaction of these inorganic constituents with the matrix of the soil involve numerous chemical reactions. So far little attention has been given to the precipitates and other solid phases that provide solubility limits of many of these inorganic elements. Recent advances in the field of soil chemical equilibria offer many opportunities for fruitful investigations in these areas. Recognizing the reactions that occur and the limits of solubility that are imposed by various reaction products, it will be possible to predict the effects of changing soil conditions on the solubility and mobility of these elements. The chemistry of each of these elements is sufficiently different that detailed investigations must be made for each element. After the major reaction products of these elemental constituents have been identified, it will then be easier to understand the effects of pH, redox equilibria, and the effect of accompanying ions of their solubility. Many of the reaction products of various elements in soils constitute complex solid phases, including isomorphous substitutions and changes from amorphous to more crystalline forms. These facts often obscure solubility relationships, especially when the specific ionic composition of the soil solution is ignored.

With the advent of specific ion electrodes and the availability of many stability constants for solid phases and ion complexes and metal chelates, it should be possible to make tremendous advances in explaining the inorganic reactions that occur in soils when waste materials are added to them. The long-term effect of adding unnatural levels of various inorganic constituents to soil will undoubtedly modify the chemical composition of many of the precipitates and the secondary clay minerals that will be present in soils in years to come. An understanding of the consequences of these additions will involve understanding the detailed soil chemistry of the secondary minerals that form in soils. Recent advances in the areas of soil chemical equilibria provide useful guidelines for initiating detailed studies in these areas of investigation. It is recommended that both practical and basic studies be combined to examine the long-term consequences of inorganic and heavy metal additions to soils through waste disposal. The basic study should help to illucidate the principles that are involved and avoid unnecessary experimentation and duplication of effort.

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Organics

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ABSTRACT

The organic components of sewage sludge are partly undecomposed substances and partly microbial cells and by-products synthesized during the treatment process. Most substances in both categories are readily biodegradable and undergo extensive decomposition when incorporated in soils.

Part of the sludge applied to soil becomes part of the soil humus after extensive modification, but most is converted to simple inorganic compounds. Sludge may contribute to soil improvement through its favorable effect on such soil properties as moisture holding capacity, structural stability, and cation retention.

Organic Composition of Sludge

Soluble Organic Matter In Sewage

Most of the organic matter in domestic and industrial sewages which contributes to the five-day BOD is soluble. For the most part this is readily converted to carbon dioxide, water, and other inorganic substances in aerobic treatment processes. Soluble organics rarely would persist more than a few days at most under conditions favorable for microbial activity. During the oxidation of this organic material there is some synthesis of microbial cells due to the rapid proliferation of bacteria and other microorganisms in the presents of available substrate. The proportion of soluble carbon which is converted to microbial tissue varies somewhat with the environmental conditions and with the composition of the sewage[3], but the synthetic efficiency is probably lower than 50 percent in most cases. In anaerobic systems the efficiency of conversion of soluble organics to bacterial cells is inherently low since oxidation of the substrate does not proceed to completion and the energy released per unit weight of substrate utilized is much lower than under aerobic conditions.

Synthesized microbial cells become a part of the insoluble organic material in the sewage being treated, but are themselves readily subject to subsequent decomposition to simple inorganic substances after death of the cells.

Insoluble Organic Matter In Sewage

During the period of high biochemical oxygen demand the decomposition of insoluble organic substances in sewage proceeds simultaneously with attack on soluble substances but the rate is somewhat slower than that of the soluble material and its contribution to overall oxygen requirement is masked. In domestic sewage and in waste from food processing plants much of the solid material is cellulosic in nature. Cellulose consists of bundles of long chains of cellobiose units linked end to end to form a linear polymer of high molecular weight and low solubility. Many microorganisms in manure have the capacity to hydrolyze cellulose chains to the simple sugar units cellobiose and glucose, which in turn are readily degraded further through normal metabolic pathways. The rate limiting step in this sequence is the hydrolysis of the cellulose chain; consequently much of the cellulosic material in sewage ends up in sludge.

Hemicelluloses, which are mixed polymers of pentoses, hexoses, and uronic acid units, often linked together in highly branched chains, as well as other insoluble carbohydrates in food and human wastes likewise contribute to sludge but to a lesser degree than does cellulose.

Fats, waxes and oils which tend to float in sewage processing may be partially incorporated into the floc and settle in sludge. These are biodegradable though not at a rapid rate.

The relative ease of biodegradation of a major part of the sludge is emphasized by the term volatile solids applied to it. These materials are not volatile in the sense of having a high vapor pressure, but are readily converted to gases, primarily CO_2, through microbial decomposition. Figure 1 shows the rate of disappearance of sludge assuming first-order kinetics and a loss rate of ten percent per day. In a batch process the rate may be somewhat higher initially, but declines to values well below the assumed value after a few days.

More information is needed on the nature and relative amounts of organic substances in sludges and on the qualitative and quantitative changes which occur during decomposition.

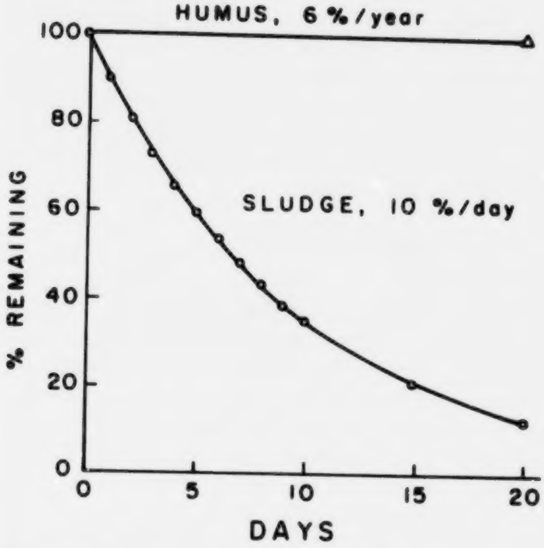

Figure 1: Rate of Decomposition of Sludge Assuming First Order Kinetics and a Loss Rate of Ten Percent Per Day.

Composition of Bacterial Cells

Bacteria are composed primarily of protein and much of the nitrogen in sludge is tied up in bacterial cells. A frequently cited formula[1] of activated sludge is $C_7H_{10}NO_3$, corresponding to about nine percent nitrogen in the organic component of the sludge. The carbon: nitrogen ratio is six, which is much narrower than is found in soil organic matter. Phosphorus and sulfur are also present in organic combination in microbial cells and in sludge, though not reflected in the simplified empirical formula.

Bacterial by-products such as slime often produced in copious quantities in sewage treatment are largely of a polysaccharide nature. This material aids in flocculation and in settling of solids and also contributes to the sludge. These polysaccharide materials themselves are not resistant to microbial attack and can be subsequently metabolized quite readily.

Soil Organic Matter and the Microbial Population of Soils

Nature and Size of the Soil Population

The micropopulation of soils is ordinarily very large, consisting of several diverse groups of organisms which are predominantly aerobic in well drained soils. The majority of forms are heterotrophic, deriving their energy material from the breakdown of organic substances. Relative numbers of the principal groups of microorganisms in surface soils are indicated below.

Organisms	*Method*	*Number per gram*
Bacteria	microscopic count	$1 - 20 \times 10^9$
	plate count	$10^5 - 10^8$
Actinomycetes	plate count	$0.5 - 15 \times 10^6$
Mold fungi	microscopic count	$3 - 50 \times 10^6$
	plate count	$.3 - 10 \times 10^5$
Algae	dilution count	$.1 - 5 \times 10^4$
Protozoa	dilution count	$10^3 - 10^5$

In addition to these forms other micro and macrofauna are often present, such as nematodes and insects.

As a result of the presence of this large and heterogeneous population of microorganisms there is intense competition in the soil for available substrate, which is normally in short supply because soil humus degrades quite slowly. The rate of decomposition of the organic fraction of soils usually is within the range of two to ten percent per year. Another aspect of the soil population which needs to be brought out is that it has the capability of metabolizing a wide variety of organic substances. Thus there are organisms that can live on gasoline and motor oil, fungi that can use both carbon and nitrogen in hydrogen cyanide, bacteria which decompose chlorinated hydrocarbon pesticides. Organic substances ranging from methane to molecules having molecular weights in the millions are converted by the soil population to simple inorganic products such as carbon dioxide, water, nitrate, phosphate and sulfate in the soil.

In the light of the foregoing, the addition of sewage sludge may be viewed as akin to throwing fuel on a smoldering fire, which results in an increased rate of combustion. Except for certain types of industrial sludges, sewage sludge represents a substrate for the soil population which is much higher on the scale of availability than is the soil humus which normally supports the soil population. However, quantitative information on the kinetics of sludge decomposition in or on soil is almost completely lacking. The influence of loading rates, methods of incorporation, effects of soil type, moisture tension, and soil temperature all need to be investigated. Obviously any investigation of environmental variables will require use of sludge which has been well characterized in terms of chemical composition.

Nature of Soil Humus

Many of the organic residues from which humus is derived, primarily of plant and animal origin, are similar to those in sewage. That is to say, these are predominantly cellulosic but with hemicellulose, lignin, chitin, protein, fats and waxes also represented. In extensive microbial decomposition the starting materials are drastically altered, resulting in an end product having properties unlike most of the plant constituents. The carbohydrate materials, being composed of sugar units, are extensively removed, leaving those substances which are more resistant to microbial attack. Humus most resembles lignin of the major plant constituents in certain of its properties including resistance to biological attack. It has a chemical structure based on aromatic nuclei with certain typical substituent groupings such as carboxyl, methoxyl, and phenolic hydroxyl.

Much of the chemistry of soil organic matter remains to be elucidated, but certain properties are known to be common to humus in soils everywhere. Among these is high molecular weight. All the evidence suggests that humus molecules are polydisperse, representing a broad range of molecular weights from perhaps 10^3 to greater than 10^6 (Table 1).

The humic acid fraction, which is extractable with alkali, probably has lower molecular weight than the non-extractable humus. The average molecular weight of soil humus may therefore be higher than the highest values reported for humic acids.

The relative proportions of carbon, nitrogen, sulfur, and phosphorus in humus are fairly constant in soils of otherwise diverse properties, as shown in Table 2 taken from Williams and Williams[5].

Another important property of soil organic matter is its high moisture retention capacity, which is often on the order of several hundred percent on a volume basis. This, of course, implies a great deal of swelling during the wetting process. In general, organic matter tends to improve the physical properties of soil. Increased permeability and greater stability of the soil structure are usually associated with increasing the organic matter level of soils. Application of sludge may increase the humus content of soils which are initially very low in this important constituent.

TABLE 1
Distribution of Molecular Weights, as Determined by Gel Filtration, In Humic Acids Extracted from Three Soils

Molecular wt.	*% of humic acid*		
	Salinas clay	*Aiken clay loam*	*Staten peaty muck*
<5000	16.6	0.0	0.0
5-10,000	38.5	39.1	26.4
10 -50,000	24.2	21.6	8.5
100,000 -200,000	0.0	5.7	9.8
>200,000	0.0	20.0	45.8

TABLE 2
Mean Ratios of C, N, S and Organic Phosphorus In Four Groups of Soils

Group	*C*	*N*	*S*	*P*
Granite	169	10	1.45	2.41
Slate	147	10	1.42	2.37
Sandstone	130	10	1.37	2.97
Calcareous	113	10	1.27	1.32

Dramatic improvement in soil physical and chemical properties may occur when sludge is applied on poor soils, as for example strip mine soil. Documentation of changes in soil properties as a result of sludge application is another area where additional research is needed.

Of particular importance in relation to sludge application to soils is the high cation retention capacity of soil organic matter, including the ability to form stable complexes with metal ions such as lead, zinc, cadmium and manganese. A comparison of the cation retention capacity of soil organic matter with the mineral fraction is given in Table 3.

Research is needed on the influence of sludge applications on cation exchange properties of soils. Of particular importance is to determine the role of soil organic matter in relation to the movement of potentially toxic heavy metals.

The substantial buffering capacity of soil organic matter which is associated with its high cation retention also has an important effect on soil chemical properties which will bear further investigation in relation to sludge disposal.

Biological Turnover of Soil Organic Matter

It is difficult to estimate the rate of turnover of soil organic matter since it is influenced by several environmental variables. The decomposition rate does not follow first order kinetics except for a brief period following addition of a fresh carbon source. Long term studies[2] show carbon loss to be described by equations of the form $C = at^m$, where t = time, a is a constant and m is a constant less than one. Nitrogen is ordinarily conserved with respect to carbon in the turnover process since the carbon: nitrogen ratios of organic materials which normally are incorporated in soil are of the order of 20 to 100 to 1. Since the equilibrium carbon: nitrogen ratio in soil organic matter usually is somewhere near ten, there is loss of excess carbon as carbon dioxide but with nitrogen being recycled many times until the ratio approaches the equilibrium value. In the decomposition of sludge, which may have carbon: nitrogen ratios less than ten, substantial quantities of organic nitrogen are mineralized and released as ammonia. Somewhat slower mineralization rates were observed by King

TABLE 3
Cation Retention Capacities of Mineral and Organic Fractions of Three Soils

Soil	*O.M. %*	*Cation exchange capacity m.e./100 g. soil*	
		Organic fraction	*Mineral fraction*
Dunkirk	9.75	18.8	7.4
Honeoye	6.57	13.3	3.2
Yates	5.70	9.4	3.4

and Morris[4] in their application of an anaerobic treatment process sludge on Bermuda grass. In this case decomposition was retarded somewhat by the fact that the sludge was not incorporated in soil. Incorporation is essential for rapid decomposition of sludge because it helps maintain the moisture content within the range favorable for microbial activity and ensures the presence of a large and heterogeneous soil population.

Virtually nothing is known of the nitrogen transformations attendant to sludge applications on soils, and these represent another area of needed research.

In the biological decomposition of humus there is some synthesis of new cells. However, the physical and chemical properties of humus do not closely resemble those of bacterial cells. The living component of the soil organic fraction is relatively small at any one time.

In the humification process, organic residues of very diverse character are converted to material which is biologically stable and which confers on the soil many desirable physical and chemical properties. The organic components of sewage sludges in the biologically active soil environment will be largely degraded but a fraction of this material after extensive modification will contribute to the organic fraction of soils and as such become indistinguishable from humus derived from other materials.

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Land Treatment of Liquid Waste: The Hydrologic System*

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ABSTRACT

The main hydrologic factors to be considered in the design and operation of land treatment systems are (1) infiltration rates, (2) response of groundwater to infiltration, (3) effect of system design and management on quality of renovated water, and (4) control of underground spread of renovated water below the water table. The last item is of special significance in high-rate systems. Principles of controlling the spread of renovated water are presented for deep and shallow aquifers. Because the performance of a land treatment system for liquid waste depends so much on the local conditions of soil, climate, and hydrogeology, pilot systems should precede any large-scale development.

INTRODUCTION

There are basically two types of systems for applying liquid waste (sewage effluent, processing plant effluent, animal waste, etc.) to land: low-rate systems and high-rate systems. With low-rate systems, about one or two inches of wastewater may be applied per week. With high-rate systems, the amounts may be in the range of several feet to several yards per week. With low-rate systems, the wastewater is usually applied with sprinklers, although surface irrigation methods such as furrows or borders can be used if the topography is favorable. With high-rate systems, the wastewater is preferably applied with basins, using water depths of several feet. On rolling land, furrows or borders on the contour or sprinkler systems may be used. Furrows or borders should be leveled to avoid runoff, unless special precautions are taken for storage or pump-back of the runoff. For both low-rate and high-rate systems, the wastewater is applied intermittently, rotating application or infiltration periods with drying or resting periods. Application schedules may range from several hours infiltration each day or every few days (low-rate systems) to infiltration and drying periods of several weeks each (high-rate systems).

The quality improvement of the wastewater as it seeps through the soil and becomes "renovated water" is usually greatest for low-rate systems. For example, if secondary sewage effluent is applied at a rate of one inch per week, the nitrogen load is of the same order as the nitrogen uptake by an actively growing crop, leaving little nitrogen in the renovated water. A disadvantage of the low-rate systems is their large land requirements, particularly if large waste discharges are to be handled (at one inch per week, 260 acres are required to apply 1 mgd). Thus, it may be advantageous to apply the wastewater at higher rates, particularly if permeable soils with high infiltration rates are available. The resulting high-rate systems have a greater impact on the groundwater, however, to minimize this impact, high-rate systems should be designed and managed to (a) produce a renovated water of as good a quality as possible, and (b) to restrict the spread of renovated water into the groundwater basin.

The following hydrologic factors should be considered in the design of land treatment systems for liquid waste:

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1. Infiltration rate.
2. Response of groundwater table to infiltration.
3. Effect of system design and management on quality of renovated water.
4. Controlling underground spread of renovated water below water table.

Infiltration Rate

Prediction

One of the key factors in the design of a land treatment system is the long-term infiltration rate that can be maintained. For sprinkler systems, this rate gives an idea of the design application rate to avoid surface runoff. For high-rate systems, this rate indicates safe hydraulic loading rates and, hence, the land requirements of the system.

The prediction of infiltration rates for disposal fields is more difficult than the prediction of "normal" infiltration rates in watershed hydrology or irrigation design where rainfall or high-quality water is used. This is because the wastewater contains suspended solids that accumulate on the surface of the soil and organic compounds that stimulate bacterial action in and on the soil. Also, the cations in the wastewater could have an unfavorable effect on soil structure. These actions all decrease the infiltration rate. The best way to determine the attainable infiltration rates for a land application system is through field trials, using the actual wastewater and application system to be employed (sprinklers, furrows, or basins). These trials may also serve to evaluate optimum amounts and frequencies of application and to determine the effectiveness of vegetation or other surface treatments of the disposal field.

Sometimes, infiltration measurements with clean water may be desirable to determine the "potential" hydraulic loading rate of a field and to compare fields as to their suitability for wastewater disposal. The usual precautions should be taken to make sure that the results are applicable to the entire field or system. Thus, cylinder infiltrometers should be of sufficiently large diameter to minimize the effect of flow divergence on the measured infiltration rate. Also, the infiltrometer (cylinder or sprinkler) should cover a sufficient area to give realistic infiltration rates in case restricting layers are present at some depth in the soil profile. When a small infiltrometer is used under those conditions, lateral flow will occur in the groundwater mound that will be formed above the restricting layer. The infiltration inside the cylinder will then be higher than the infiltration rate for a large area, where lateral flow above the restricting layer cannot occur.

Care should be taken when using infiltrometers on sloping land with shallow soil. In such cases, the infiltration capacity of the field may be determined by how much water can flow downhill as subsurface runoff in the soil above the restricting layer. If water is applied to a small area, as with an infiltrometer, all the water that infiltrates may easily move downhill as subsurface runoff. However, if larger areas are wetted, the subsurface runoff may not be sufficient to dispose of all the infiltrated water. In that case, the soil becomes saturated to field surface and surface runoff will occur. The actual infiltration rate is then only a fraction of that indicated by a small infiltrometer.

Where restricting or impermeable layers are present in the soil, it may be better to predict the potential infiltration rates from measurements of the hydraulic conductivity profile of the soil. Techniques are available for field measurement of hydraulic conductivity at different depths, above as well as below a water table[1]. The final infiltration rate can then be calculated by applying Darcy's equation to the one-dimensional flow system. If the field is sloping and the applied wastewater can only move away laterally as subsurface runoff, the potential subsurface flow can be computed. This value can then be divided by the proposed width of the infiltration strip (on the contour) to obtain an estimate of the safe application rate.

The actual average long-term infiltration rate on "hydraulic loading" for wastewater will be less than the potential rates because of clogging by suspended solids and biological action, and the need for drying or resting periods. Also, the ionic composition of the wastewater may cause deflocculation of the clay in the soil and associated decrease in the hydraulic conductivity. The relationship between potential and actual infiltration should be developed for various wastes, soils, and climatic conditions, so that potential infiltration rates can be converted into design application rates for wastewater disposal systems. For a high-rate system west of Phoenix, Arizona[2,3], for example, secondary effluent is infiltrated from basins at a water depth of one foot using schedules of two to three weeks flooding alternated with 10 to 20 days drying. The long-term hydraulic loading was found to be about 23 percent of the potential infiltration rate (i.e., 350 ft/yr versus 1,500 ft/yr). Similar data should be obtained for other systems.

Soil Clogging

Land disposal of liquid waste invariably causes clogging of the soil and resulting decline in infiltration rates. Clogging occurs on the surface, when suspended solids do not move into the soil. Fine, suspended matter may actually move some distance into the soil, particularly in coarse textured soils. Bacteria growing on the soil surface and in the soil pores may also contribute to a permeability decrease because of the space they occupy and the products they form (including gases). High dissolved BOD-values may cause serious clogging problems because of the bacterial activity they stimulate.

If clogging of the soil surface is caused by an inert material, the impedance of the clogged layer can be expected to increase linearly with the total solids load, assuming that the clogged layer builds up uniformly. Since the clogged layer may become more compact as the total solids load increases, however, the impedance of the clogged layer may actually increase more rapidly than the total solids load[4]. This is particularly true if the hydraulic gradients at the soil surface are relatively high. The clogged layer is then subjected to a seepage force which causes compaction of this layer.

An unfavorable situation occurs where coarse soil overlies finer soil. In that case, particulate matter may move through the coarse upper layer and settle out on the finer soil layers further down. The clogging caused by this is out of reach of the drying influence of the sun or the mechanical influence of spikes or disks of cultivators. Thus, it may take a very long time of "resting" the system before the effects of deep clogging on infiltration are alleviated. The same is true for gravel layers or mulches. These may increase infiltration rates initially, but their effectiveness decreases with time. Once they are clogged with solids, the infiltration rate is difficult to restore[2].

The depth and extent of the clogged zone can be evaluated with tensiometers installed in the soil at different depths[2]. Soil clogging occurs where the hydraulic gradients increase with time. A quick way of assessing where clogging occurs is to flood an area of soil and measure the effect of water depth on infiltration rate[2]. Applying Darcy's equation to the infiltration system shows that if the infiltration rate increases essentially linearly with the water depth, the clogged layer is thin and at the surface of the soil. However, if the infiltration rate is not as sensitive to water depth, clogging takes place at greater depths or over a greater distance in the soil profile.

Surface clogging is the easiest to control or prevent. Drying, harrowing, scraping, etc., are some of the practices that have been effectively used to reduce the hydraulic impedance of the clogged layer. Of course, the best way to control clogging is to prevent it by minimizing the suspended soils content of the wastewater, for example, by using settling basins and, if needed, flocculants, filtration, or both. For sewage effluent, the suspended solids content should not be much greater than 10 mg/l if high infiltration rates are to be maintained[4].

Where the wastewater is applied with sprinklers, clogging should not be allowed to progress to the point where runoff begins to occur. Runoff may also be produced by high-intensity rainfall. Where this can be expected, the suspended solids content of the wastewater should be as low as possible to minimize transport of accumulated solids from the field into surface water. Level basins, furrows, or borders do not pose a runoff hazard if they are designed to store expected rainfall within the confines of their dikes and ridges.

Scheduling Infiltration and Dry Periods

With continued application of wastewater, clogging causes the infiltration rates to eventually become so low that a drying or resting period is necessary to restore the infiltration rates. Such drying will allow dessication and decomposition of the clogging material, which is usually effective to give complete recovery of the infiltration rate[2,3]. Occasionally, some mechanical treatment such as scraping the surface to remove accumulated solids, disking, or raking, or an extra long dry period may be necessary.

If it is desirable to minimize the land area required for the disposal system, the optimum combination of infiltration and drying periods should be evaluated. The application of wastewater should be stopped before the infiltration rates become too low, and it should not be resumed until the infiltration rates have made reasonable recovery. If the decrease in infiltration during application and the recovery in infiltration during drying are known, the combination of application and resting periods yielding maximum long-term infiltration or hydraulic loading can be evaluated. Since the optimum combination of infiltration and dry periods depends so much on the climate, the type waste, and the soil characteristics, it can best be evaluated by local experimentation.

Combinations used in actual practice include a few hours infiltration every 24 hours (for processing wastes), about 4 to 12 hours infiltration every week (low-rate systems for sewage effluent), and infiltration and drying periods of several weeks each (high-rate systems for sewage effluent).

Role of Vegetation

Vegetation is generally desirable for disposal fields because it removes nutrients and other constituents (metals, etc.) that entered the soil with the wastewater. Vegetation may also be effective in stimulating denitrification in the root zone causing additional nitrogen removal from the soil[2,3].

Vegetated soils also dry to greater depths and to a lower water content than non-vegetated soils during the growing season. This will increase the oxygen diffusion rate and allow more oxygen to penetrate deeper into the soil during drying.

Vegetative covers (Reed canary grass, bermudagrass, etc.) for the disposal fields are usually recommended where wastewater is applied with sprinklers. This protects the soil surface against the direct impact of the drops, which could otherwise have an adverse effect on the structure of the surface layer and, consequently, on the infiltration rate. Vegetation also intercepts some of the suspended solids, leaving less solids to accumulate on the soil surface. New growth of vegetation may break the continuity of impeding layers on the soil surface, which in turn should have a beneficial effect on the infiltration rate. Vegetation also reduces soil erosion and the amount of solids that may be washed off a disposal field with surface runoff.

Where the wastewater is applied with basins, a disadvantage of vegetation is that it restricts the water depth that can be used in the basin. This will in turn result in lower infiltration rates, particularly where the infiltration rate varies almost linearly with water depth, due to surface clogging. On the other hand, a shallow depth of water may be an advantage if it allows enough light to penetrate to the bottom for algal growth. When algae grow on the bottom, pieces of the algal mat may actually float up when oxygen bubbles become entrapped in the mat. Since suspended solids are carried up with the fragments of the algal mat, this process "rejuvenates" the bottom of the basin and has been observed to actually increase the infiltration rates[4]. When vegetation is used in the basins, flooding and drying periods may have to be scheduled so as to allow the vegetation to develop and survive. The resulting flooding and drying schedules may not be the most desirable from a standpoint of maximizing infiltration, maximizing nitrogen removal by denitrification, or both. Thus, maximum infiltration is probably obtained with relatively deep, non-vegetated basins, particularly if the wastewater is relatively clear to allow sufficient light to penetrate to the bottom.

Climate

Climate affects infiltration rates through the effect of temperature on the viscosity of the wastewater and through the effects of rain and temperature on the recovery of infiltration rates during drying. Since infiltration rates are inversely proportional to the viscosity, a decrease in temperature will cause a decrease in infiltration rate. A temperature drop from 80°F to 50°F, for example, will cause an infiltration reduction of about 34 percent to the change in viscosity. Also, lower temperatures reduce the rate of drying of the soil and of the clogged layer and the rate of decomposition of organic clogging materials. Thus, longer drying or resting periods will be required to restore infiltration rates. Rainfall during resting periods may also reduce the rate of infiltration recovery, particularly if the rain falls during the early part of the resting period and solids have not yet completely dried. Where the internal drainage of the soil is a restricting factor, rain may have to be subtracted from the hydraulic loading rate. This can be a significant factor for low-rate systems on fine-textured or poorly drained soils.

Temperature has an effect on the biological and chemical processes taking place in the soil. For example, decomposition reaction rates may be reduced 50 percent for each 10°C drop in temperature. Denitrification rates may be reduced more than nitrification rates when temperatures drop below 10°C. This could cause the system to remove less nitrogen from the wastewater when temperatures are low.

Response of Water Table to Infiltration

In the long run, wastewater can be applied to the soil no faster than the internal drainage rate of the soil. Where a restricting layer is present at some depth and the infiltration rate is higher than the rate of water movement through this layer, a perched water table will form and rise above the restricting layer. This water table will continue to rise until the rate of water movement through the restricting layer equals the infiltration rate. When the water table reaches the soil surface, the infiltration rate becomes equal to the rate of water movement through the restricting layer. At this point a sharp decrease in infiltration may occur which can lead to surface runoff. The effects of perching mounds or restricted subsurface runoff should be considered when selecting safe hydraulic loading rates, as mentioned in the section on predicting infiltration rates.

Rising water tables can also occur if the hydraulic conductivity of the aquifer is fairly low or the aquifer is relatively shallow and the groundwater moves essentially in horizontal direction. Thus, an analysis of the groundwater flow system below the disposal fields should be made to make sure that the aquifer can transmit the infiltrated water at a sufficient rate to avoid build-up of groundwater mounds.

To ensure rapid drainage of the soil profile during drying, which is necessary for effective oxygenation of the soil, the groundwater mound should not be allowed to rise closer to the soil surface than a distance of about four feet, unless the mound rapidly recedes after infiltration is stopped.

In soils with restricted drainage, such as shallow or slowly permeable soils, an artificial drainage system may be needed for rapid lowering of the water table when drying is started. Drainage systems may also be needed to prevent groundwater tables from rising to the surface and restricting infiltration rates while wastewater is being applied. Such drainage systems can be designed in the same way as agricultural drainage systems.

Effect of System Design and Management on Quality of Renovated Water

The infiltration rate, the length of infiltration and resting periods, and the way the wastewater is applied (flooding or sprinkling) all have an effect on the quality improvement of the wastewater as it moves down through the soil and becomes renovated water. The lower the infiltration rate, the faster the quality of the renovated water will improve in relation to distance of percolation through soil. This can be an important factor if the soil is fairly shallow or most of the quality improvement needs to be obtained in the first few feet of travel. If deep soils are present or if the renovated water goes through long times and distances of underground travel before it leaves the aquifer (via springs, streams, lakes, drains, or wells), the additional removal of phosphate, fluoride, metals, organic carbon, and other constituents by the extra underground travel may still produce renovated water of acceptable quality.

The length of infiltration and drying or resting periods may affect the form and concentration of the nitrogen in the renovated water. If the nitrogen occurs as nitrate in the wastewater and if organic carbon in the wastewater is sufficient for complete denitrification, denitrification can be obtained by applying the wastewater long enough to deplete the oxygen in the upper soil layers. The organic carbon will then be present in anaerobic zones in the soil where it is available for the denitrifying bacteria. If such wastewater is applied in frequent, small amounts, the soil may be sufficiently aerobic to cause at least part of the organic carbon to be oxidized by heterotrophic aerobic bacteria, leaving less for denitrification and hence causing more if not all of the nitrogen to remain as nitrate.

If the nitrogen is mainly in the ammonium form in the wastewater and organic carbon in the wastewater is not abundant, denitrification can be maximized by continuing the application of wastewater long enough to deplete the oxygen in the soil and to stop nitrification of the ammonium[2,3,5,6]. The ammonium will then be adsorbed by the cation exchange complex in the soil. Before this complex becomes saturated with ammonium, a resting period should be started during which the adsorbed ammonium can be nitrified. Part of the nitrates thus formed can be denitrified as oxygen is used up in the unsaturated zone. If such wastewater were applied in frequent, small amounts, the upper part of the soil would be mostly aerobic which would yield essentially complete nitrification of the ammonium and oxidation of the organic carbon. In that case, essentially all the nitrogen in the wastewater will be converted to nitrate with little or no subseqent denitrification[2,3,5]. If organic carbon in the wastewater is abundant, however, enough may be left for significant denitrification when the wastewater moves into the deeper, anaerobic zones[7].

The low oxygen levels in the soil, mentioned in the previous paragraphs, are readily obtainable if the wastewater is applied with basins or other flooding techniques. If the wastewater is applied with sprinklers, the drainage of the soil between sprinkler revolutions may draw sufficient oxygen into the soil to maintain aerobic conditions in the upper portion of the profile, particularly in rapidly draining soils. Under those conditions, nitrogen removal by denitrification may be difficult to achieve if the wastewater contains relatively small amounts of organic carbon[8].

Controlling Underground Spread of Renovated Water

The quality of the renovated water will usually be inferior to that of the native groundwater, even when the land treatment system is managed to obtain the best quality renovated water achievable. Where there is a concentrated source of renovated water entering the groundwater, such as with high-rate systems, provisions may be needed to restrict the spread of renovated water into the groundwater basin. This can be accomplished by taking the renovated water out of the aquifer at some distance from where it entered the groundwater, as happens naturally when the groundwater drains to a stream or a lake (Figure 1). If the renovated water does not leave the aquifer in a natural manner, it should be collected by drains (for

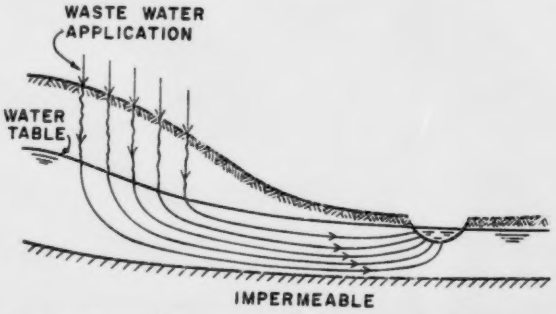

Figure 1: Renovated Wastewater Draining Naturally Into Surface Water.

shallow aquifers) or wells (for deep aquifers) to limit its spread into the aquifer. After collection (and additional treatment if necessary), the renovated water may be used for irrigation, recreation (including lakes), industrial, and perhaps municipal purposes, or it may be discharged into surface water. With these systems, a portion of the aquifer is essentially used as a natural filter.

The proper distance between the point where the wastewater enters the soil and where it leaves the aquifer as renovated water depends on the type wastewater, the desired quality of the renovated water, and the nature of the soil and aquifer materials. For granular soils and aquifers, underground travel distances of several hundred feet and underground detention times of several weeks may be sufficient to yield a renovated sewage effluent of suitable quality. The more time and distance of underground travel are allowed, the better the quality of the renovated water will be, at least to a certain limit. Most of the quality improvement, however, takes place in the first few feet of the soil profile.

Deep Aquifers

When the aquifer is unconfined and relatively deep, a "closed" wastewater renovation system can be obtained by concentrating the areas where the wastewater is applied to the land in two parallel "infiltration strips" (Figure 2). The renovated water can then be pumped from wells midway between the strips. Other possibilities are a single infiltration strip with wells on both sides, or a central infiltration area surrounded by a ring of wells (Figure 3). The wells in the two systems of Figure 3 will pump a mixture of native groundwater and renovated wastewater. This may be desirable if the use of the pumped water requires dilution of the renovated water anyway. However, if recovery of renovated water is the main objective of the wells, the additional native groundwater increases the pumping costs and constitutes an extra draft on the native groundwater.

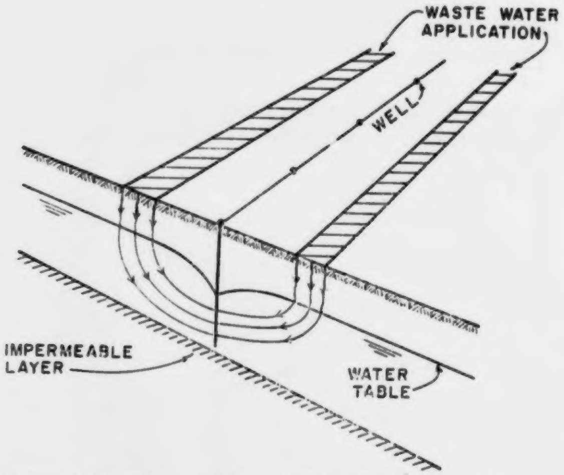

Figure 2: Schematic of Two Parallel Strips (Hatched Area) for Applying Wastewater and Wells Midway Between the Strips for Pumping Renovated Water from Deep Aquifer.

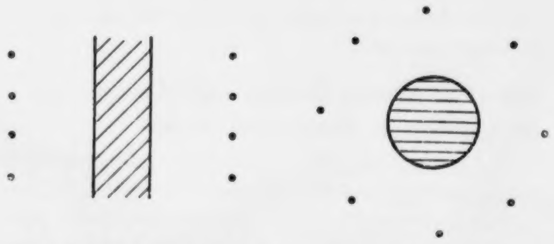

Figure 3: Long Infiltration Strips (Hatched Area) with Wells on Both Sides (Left) and Circular Infiltration Area Surrounded by Wells (Right).

The design and operation of a wastewater renovation system consisting of two parallel infiltration strips and wells midway between the strips (Figure 2), should be based on the following three criteria:

1. The water table below the infiltration strips should not rise to field surface where it can restrict the infiltration rates. Preferably the water table should not come closer to field surface than a distance of about four feet. This enables rapid drainage of the soil profile, and hence entry of oxygen, when infiltration periods are rotated with dry or resting periods.
2. All wastewater that has infiltrated should be pumped as renovated water from the wells. No renovated water should move into the aquifer outside the system of infiltration areas and wells.
3. The renovated water should have had the proper time and distance of underground travel when it reaches the wells.

In order to investigate whether a certain design meets these three criteria, the underground flow system must be predicted. This will also yield an estimate of the pumping lift in the wells.

The prediction of the underground flow system for renovation systems as in Figure 2 requires knowledge of the rate of entry of wastewater into the soil and of the hydraulic properties of the aquifer. The infiltration rates may be evaluated by local experimentation as previously explained. The main hydraulic property to be evaluated for the aquifer is the effective transmissibility for groundwater recharge, which will govern the flow system under and near the infiltration strips.

The effective transmissibility for groundwater recharge is less than the total transmissibility of the aquifer, particularly for relatively deep, unconfined aquifers, because recharge flow systems are characterized by an upper, active zone, and a lower, passive zone[9,10]. The effective transmissibility for recharge depends on the width of the infiltration strip. It increases essentially linearly with that width until it has become equal to the total transmissibility of the aquifer. Once the underground flow has become mainly horizontal, such as in the vicinity of the wells (Figure 2), the total transmissibility of the aquifer can be used to analyze the rest of the flow system[10]. If the wells do not completely penetrate the aquifer, the appropriate correction factors should be applied to the total transmissibility.

A good way to evaluate the effective transmissibility of an aquifer for groundwater recharge is from the response of groundwater levels to infiltration, as may be determined in an experimental recharge project[10]. This was done for the Flushing Meadows Project in the Salt River bed, west of Phoenix, Arizona, where renovation of secondary sewage effluent by land application is studied with six parallel recharge basins covering a block of 220 x 700 feet[2,3]. Two observation wells, one 30 feet deep and the other 100 feet deep, were installed in the center of this block. The response of the water levels in these wells to infiltration was simulated on an electrical analog, which then yielded the hydraulic conductivity of the aquifer in vertical and horizontal directions[10]. The resulting values agreed with data obtained from direct permeability measurements on seven observation wells in the project[10].

Since the directional permeability components of the aquifer were known, the theoretical shape of the groundwater mound could be evaluated by electrical analog[10]. The Dupuit-Forchheimer theory was then applied to this mound to obtain the effective transmissibility of the aquifer for the recharge flow system, which was only 12 percent of the total transmissibility[10]. This effective transmissibility, corrected for the width of the infiltration strip, was used in analog analyses of flow systems for the prototype system (Figure 2) to predict the shape of the water table and to construct a network of streamlines and equipotentials[10]. When a certain porosity of the aquifer material was assumed, the macroscopic velocities of the water from one equipotential to the next could be determined for each stream tube, which in turn yielded estimates of the total underground travel time of the renovated water[10]. The procedure was applied to various designs so that the optimum layout of infiltration areas and wells could be selected[10]. Similar procedures can be applied to the design of other high-rate, closed wastewater renovation systems.

Shallow Aquifers

If the water table and the impermeable layer are relatively close to field surface, wells may not be effective and the renovated water is better collected by open or closed drains. The system could consist of two parellel strips where the wastewater is applied to the soil with a drain midway between the strips (Figure 4A), or of a series of infiltration strips and drains (Figure 4B). Since infiltration periods are usually rotated with drying periods, short underground travel distances and detention times can be avoided in the system of Figure 4B by closing the drains below the strips receiving wastewater and collecting the renovated water with the drains below the drying strips. These drains will be closed, and the other drains opened, when infiltration and drying periods are rotated (Figure 4C).

The water table in the systems of Figure 4 should preferably not rise so high that it reaches the soil surface in the infiltration areas and reduces the infiltration rates. The shape of the water table in these systems can be calculated with drainage theory[11]. Using the Dupuit-Forchheimer assumption of horizontal flow and assuming a uniform infiltration rate, the following equation can be derived for the flow system between the infiltration area and the drain (Figure 5).

$$H_c^2 = H_d^2 + \frac{IW}{K} K (W + 2L)$$

where

H_c = height of water table above impermeable layer at outer edge of infiltration strip for systems as in Figure 4A and at center of infiltration strip for systems as in Figure 4B.
H_d = height of water table above impermeable layer at drain
I = infiltration rate (length/ time)
W = width of infiltration strip for systems as in Figure 4A and one-half width of strip for systems as in Figure 4B.
K = hydraulic conductivity of soil (length/ time)
L = distance between edge of infiltration strip and drain

The term W refers to the longest horizontal distance of travel for the water beneath the infiltration strip. If the drain is running free, H_d will be equal to the height of the center of the drain above the impermeable layer. However, if a back-pressure is maintained in the drain (which is sometimes done to exclude air and to avoid deposits of iron or manganese oxides in the drain), H_d is the height of the drain above the impermeable layer, plus the back-pressure head.

Knowing H_d, I, and K, the value of H_c can be calculated for various combinations of W and L. Thus,

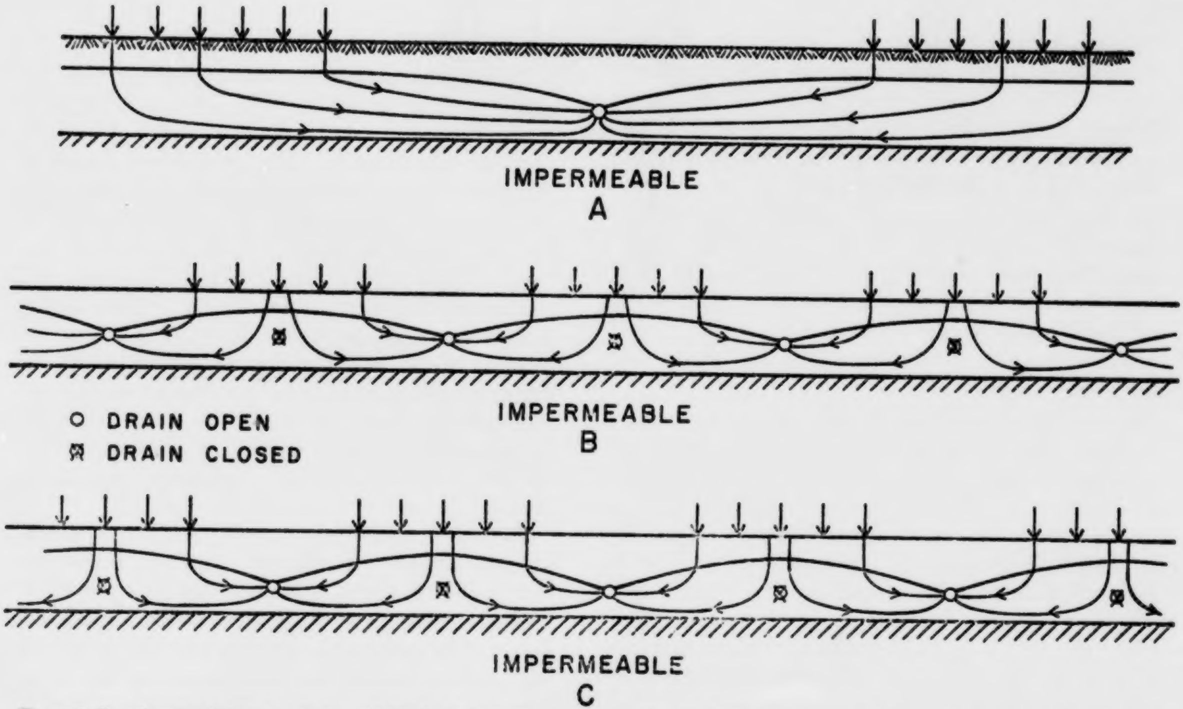

Figure 4: Two Parallel Infiltration Strips with Drain Midway Between Strips (A) and Continuous System of Infiltration Strips and Drains with Alternate Infiltration and Drying (B and C).

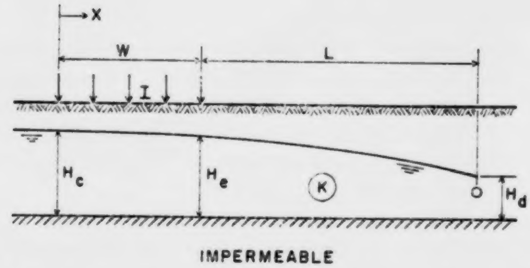

Figure 5: Geometry and Symbols for Parallel Infiltration Strip and Drain.

the optimum combination of W and L whereby H_c does not exceed a preselected value can be evaluated. If the wastewater is applied to the soil with infiltration basins and the groundwater table is so high that it coincides with the water surface in the basins, the equation can be used to calculate the average infiltration rate in the basin. To obtain sufficient time and discharge of underground travel for the water in the systems of Figure 4B, certain modifications may have to be incorporated.

The equation applies to relatively shallow systems. Where the impermeable layer is at sufficient depth to render the horizontal-flow theory invalid, equivalent depths of the impermeable layer should be used as is done in the design of agricultural drainage systems[12].

Pilot Projects

The performance of a low-rate or high-rate system for applying wastewater to soil is very much dependent on the local conditions of climate, topography, soil, and hydrogeology. Unless similar projects already exist in the area, it is very desirable to experiment with a small pilot project before going into any large-scale development. The results from the experimental project can then be used as input information for the design and management of the operational system. Experimentation with a pilot project could well save a lot of disappointment and money later on. Finally, the best designed system for applying wastewater to land will still be a failure if it is not properly managed.

SUMMARY AND RESEARCH RECOMMENDATIONS

The hydrologic aspects of systems for applying liquid waste to land are basically covered by irrigation and drainage theory. Factors to be considered include (a) the design application or infiltration rates in relation to the hydraulic acceptance of the soil, the desired quality improvement of the water, and the intended longevity of the system, (b) the most appropriate system for applying the wastewater, and (c) the groundwater management below the receiving fields. While most irrigation and drainage principles are generally known, there is still need for additional research on many of these aspects. Because the performance of a land treatment system depends so much on the local conditions of soil, climate, and groundwater geology, local research and pilot systems should usually precede large-scale developments.

Additional research is needed to determine the effect of the application system itself on the hydraulic loading rate and the quality improvement of the wastewater as it moves through the soil. The loading rates and oxygen regimes for flooded and sprinkled soils are not the same, for example, and this may influence denitrification, immobilization of heavy metals, and other reactions. More research is needed on the optimum treatment of the wastewater before it is applied to the land. If the water is to be reused, the soil filtration process may not yield renovated water of sufficient quality at high loading rates. In that case, studies should be made to determine the optimum combination of treatment of the water before and after it has moved through the soil.

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Land Resources

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ABSTRACT

Soil, climatic, geologic, and institutional factors have to be considered in selecting sites for waste disposal on land. Runoff, erosion, permeability, infiltration capacity, and available water holding capacity are important soil properties that have to be considered. The balance and distribution of precipitation and evapo-transpiration are important climatic considerations, and lithology, jointing, and groundwater relationships are important geologic factors. Availability of public land and farm size must also be taken into account. Soil surveys conducted by the Soil Conservation Service of the United States Department of Agriculture and its cooperators can be used for evaluating the feasibility of disposal systems and for locating sites. Soils suitable for waste disposal are available near most metropolitan areas but the ecological, economic, and institutional factors are more favorable in the arid western United States.

INTRODUCTION

Disposal on land may substitute for secondary and tertiary treatment of liquid wastes and serve as the means of processing the residues (sludge) of secondary and tertiary biological or chemical waste processing systems. In either case the waste must be destroyed or absorbed in the soil and any effluent must not contribute to the degradation of our water and air resources. Land-based disposal systems must be close to sources of effluents and they must be institutionally acceptable. Finally, any system must be capable of being operational long enough to amortize its cost.

In this paper the land-related requirements of such a system, soil, climate, geology, institutional factors, and the availability of land meeting these requirements are discussed.

Soil Factors

Soil can fulfill many functions in a waste disposal system. It can provide a medium in which organic compounds can be oxidized and the BOD dissipated. It can provide a combination of oxidizing and reducing environments in which nitrogenous compounds are first oxidized and then reduced to nitrogen gas. The soil may absorb and inactivate inorganic compounds such as phosphates and some heavy metals and it may serve as a filter for pathogens and as a medium for oxidizing them. Water may move through the soil, be filtered, and be used to recharge the groundwater supply. If a crop is grown on the soil, the water may be largely evaporated and very little or no water may percolate or run off. Soluble salts are either precipitated in the soil or are taken up by the plants and recycled if the crop is used for feed.

All soil has some of these capabilities. But deep soils that have a large total surface area and contain much clay and organic matter absorb and filter wastes more effectively than shallow, sandy soils. But soil must also have the ability to accept the wastes. Liquid wastes must be able to infiltrate and percolate the soil, and vehicles delivering sludge or solid waste must be able to enter the disposal site during all times of the year. These requirements are best met by relatively coarse, sandy soil that, unfortunately, has only limited capability to adsorb and filter. Hence, the requirements for soil as a medium for waste disposal are conflicting and even the best site, found after a long search, will be a compromise.

Soil surveys, prepared by the Soil Conservation Service of the United States Department of Agriculture in cooperation with agricultural experiment stations and units of local government, can be of help in this search. Soil scientists making soil surveys not only make maps but they also evaluate the usefulness of individual soils for specific purposes. Criteria for evaluating soils for many uses have been established, and ratings of individual soils for these uses are included in modern published soil surveys.

A guide for assessing the suitability of kinds of soil as media for disposal of wastes has been prepared and is being tested. Although this guide is aimed primarily at farm and food processing wastes, it is also relevant to municipal and some industrial disposal systems. Slightly modified summary tables from this guide are reproduced in Tables 1 and 2. Six soil properties—permeability of the most limiting subsoil layer, infiltration rate, soil drainage, runoff, flooding, and available water holding capacity—are used to rate kinds of soil as having slight, moderate, or severe limitations for use for waste disposal. Most of these criteria are self-explanatory except for available water holding capacity. This criterion, measured in

TABLE 1
Soil Limitations for Accepting Nontoxic Biodegradable Liquid Waste[1]

Item[2]	*Degree of soil limitation*		
	Slight	*Moderate*	*Severe*
Permeability of the most restricting subsoil horizon to 60 inches	Moderately rapid and moderate 0.6-6.0 in./hr.	Rapid and moderately slow 6-20 and 0.2-0.6 in./hr.	Very rapid, slow, and very slow > 20 and < 0.2 in./hr.
Infiltration	Very rapid, rapid, moderately rapid, and moderate > 0.6 in./hr.	Moderately slow 0.2-0.6 in./hr.	Slow and very slow < 0.2 in./hr.
Soil drainage	Well drained and moderately well drained	Somewhat excessively drained and somewhat poorly drained	Excessively drained, poorly drained, and very poorly drained
Runoff	None, very slow, and slow	Medium	Rapid and very rapid
Flooding	Soil not flooded during any part of the year	Soil flooded only during nongrowing season	Soil flooded during growing season
Available water capacity to 60 inches or to a limiting layer T[3]	> 7.8 inches	3-7.8 inches	< 3 inches
P[4]	> 3 inches		< 3 inches

[1] Modified from a draft guide for use in the Soil Conservation Service, USDA.

[2] For definitions see the *Soil Survey Manual*, U.S. Department of Agriculture Handbook No. 18, 1951.

[3] Temporary Installation.

[4] Permanent Installation.

TABLE 2
Soil Limitations for Accepting Nontoxic Biodegradable Sludges and Solids[1]

Item[2]	*Degree of soil limitations*		
	Slight	*Moderate*	*Severe*
Permeability of the most restricting layer above 60 inches	Moderately rapid and moderate 0.6-6.0 in./hr.	Rapid and moderately slow 6-20 and 0.2-0.6 in./hr.	Very rapid, slow, and very slow > 20 and < 0.2 in./hr.
Soil drainage	Well drained and moderately well drained	Somewhat excessively drained and somewhat poorly drained	Excessively drained, poorly drained, and very poorly drained
Runoff	None, very slow, and slow	Medium	Rapid and very rapid
Flooding	Soil not flooded during any part of the year		Soil flooded during some part of the year
Available water capacity from 0 to 60 inches or to a limiting layer	> 7.8 inches	3-7.8 inches	< 3 inches

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[1] Modified from a draft guide for use in the Soil Conservation Service, USDA.

[2] For definitions see the *Soil Survey Manual*, U.S. Department of Agriculture Handbook No. 18, 1951.

inches for the whole soil, is the depth of the layer of water that would be formed if all water in the soil that can be used by plants were concentrated at the soil surface. The equivalent volume measure would be the acre-inch (27,000 gallons) or the acre-foot (326,000 gallons). Available water holding capacity used in this way integrates the effects of soil texture and depth and is a convenient measure for effective soil volume. It should be noted that in this guide severe limitations reflect limiting capacity of the soil to accept wastes and limited capability of the soil to render wastes harmless to the environment. Rapid and slow permeability, for example, are both considered severe limitations. Separate criteria for effluents and for sludges were developed. The two sets of criteria differ only slightly; in rating soils for liquid waste-disposal systems infiltration rate is added as a criterion and class limits for available water holding capacity are made less restrictive. Requirements for water holding capacity are more stringent for sludge disposal if a crop is to be grown on the site and for liquid waste disposal if no permanent irrigation system is installed.

A meaningful national summary of soils judged suitable for waste disposal by these criteria could not be presented in the time available at the meeting. Instead, I showed a soil map of the United States that had been modified to show broad areas where the dominant soils have certain limitations for waste disposal. The relationship of these areas to the major population centers was self-evident.

Areas including large parts of the Atlantic Coastal Plain, the Mississippi Delta, extensive areas in southern Illinois, areas around the Great Lakes, and in Minnesota were shown as wetness being a primary limitation. All these areas except the one in Minnesota contain major metropolitan areas and areas of rapid urban growth such as in Florida. Areas in which pollution because of soil slope and the concomitant hazard of erosion or because of shallow soils is a major hazard were also shown. They are concentrated in the major mountain systems of the country. Since the mountainous topography has also been a major restraint for urban development these areas contain relatively few of our major metropolitan centers. In relatively inextensive areas of sandy soils, excessive permeability and limited filtering and absorptive capacity are dominant soil limitations. Although these areas are inextensive, they present a potential pollution hazard. The soils in these areas have the capacity to accept large amounts of liquid waste and they are presently not used intensively. This and the ownership patterns in these areas tempt their use for large-scale, land-based disposal systems. This may eventually lead to serious pollution problems. Soils of this kind are reasonably extensive near the Chicago metropolitan area.

Areas in which slow permeability of the dominant soil is the major limitation are similarly inextensive. But they are a problem for using soils for land-disposal systems in the Dallas-Ft. Worth and the San Francisco metropolitan areas.

One must realize that a map of this scale can give only very general information on broad areas. An area shown on the map as having certain limitations may still contain extensive areas that are well suited to waste-disposal systems. As a rough estimate we can say that in the area of wet, sloping and mountainous, and sandy soils discussed so far two-thirds of the soils are poorly suited for waste-disposal systems but one-third are suited. The situation is further complicated by variations in the size of suitable units. Suitable inclusions in areas of predominantly sloping and shallow soils, for example, tend to be in small units in the Appalachian Mountains and in rather large units in the deserts of the Southwest.

In large parts of the country, primarily in the middle and upper coastal plain of the Atlantic and Gulf coast and in much of the Midwest, the dominant soils are suitable for waste-disposal systems but their permeability is slow enough that liquid wastes can be applied only at moderate rates. In addition, up to one-third of the soils in these areas are unsuitable for waste-disposal systems. These areas include many of the major urban centers of the Southeast and the Midwest, including the industrial areas along the Great Lakes. Finally, there are areas in which most soils appear to be well suited for waste-disposal systems. Few of these areas are near major metropolitan areas.

This overview of the country gives a very general picture of the soil resources available for the country as a whole, but it is not useful for local planning or site selection. For local planning and site selection soil surveys are available for about 40 percent of the country. Individual soil surveys usually cover counties. They consist of detailed soil maps, usually at a scale of 1:31,680 to 1:15,840, on a halftone photographic background, a general soil map of the whole county, technical descriptions of the soils, measured and estimated data on the agronomic and engineering properties of soils and ratings of individual kinds of soil for the various purposes that have been discussed. Soil scientists of the Soil Conservation Service and of state agricultural experiment stations can advise on criteria for selecting suitable soils and sites. Areas that are selected from a detailed soil survey must, of course, be further evaluated by onsite investigations.

Climatic Factors

Temperature and precipitation, both amount and distribution, affect the feasibility and design of disposal systems. During the cold season there is little microbial activity to decompose wastes and little evapo-transpiration to remove water. Temperature regime is not an insurmountable factor, but holding tanks for the wastes that accumulate during the cold season and areas for disposing the accumulated wastes during the warm season add to the cost and the acreage requirements of systems. Precipitation or, more correctly, the balance of precipitation and potential evapotranspiration presents a more serious problem. Solid waste and sludge disposal systems need moisture for micro-organisms and plant cover and for leaching salt from the root zone. Solid waste and sludge disposal systems in arid parts of the country require supplemental irrigation. Excessive leaching in humid parts of the country must be avoided. In liquid waste disposal systems the waste water may be of considerable value, depending on the objectives of the system. The effluent can recharge aquifers if this is an objective of the system or it can make up for a water deficit if recycling of wastes and crop production are objectives. The effluent may, however, tax the absorptive capacity of a system if the excess water is added to a large natural precipitation. In some systems the value of the waste water for irrigation is expected to help defray part of the cost of the disposal system or to entice farmers to allow use of their land. This value can be realized only if there is a moisture deficit.

In designing a system, the total amount of precipitation relative to evapotranspiration, the distribution of precipitation during the year, and the changes in precipitation from year to year have to be considered. Figure 1 shows the excess of mean annual potential evapotranspiration as estimated from Thornthwaite's formula over mean annual precipitation for the United States. The values are in inches. Positive values, in the western part of the country, indicate excess evapotranspiration as high as 70 inches. Obviously, the higher the excess of evapotranspiration, the more waste water can be added to the land without causing leaching and the greater is the value of the waste water for irrigation. To the east of a line running slightly to the west of the Mississippi River, negative values suggest some runoff and leaching even if no waste water is added to the soil. Actual excesses and deficits depend, largely, on the distribution

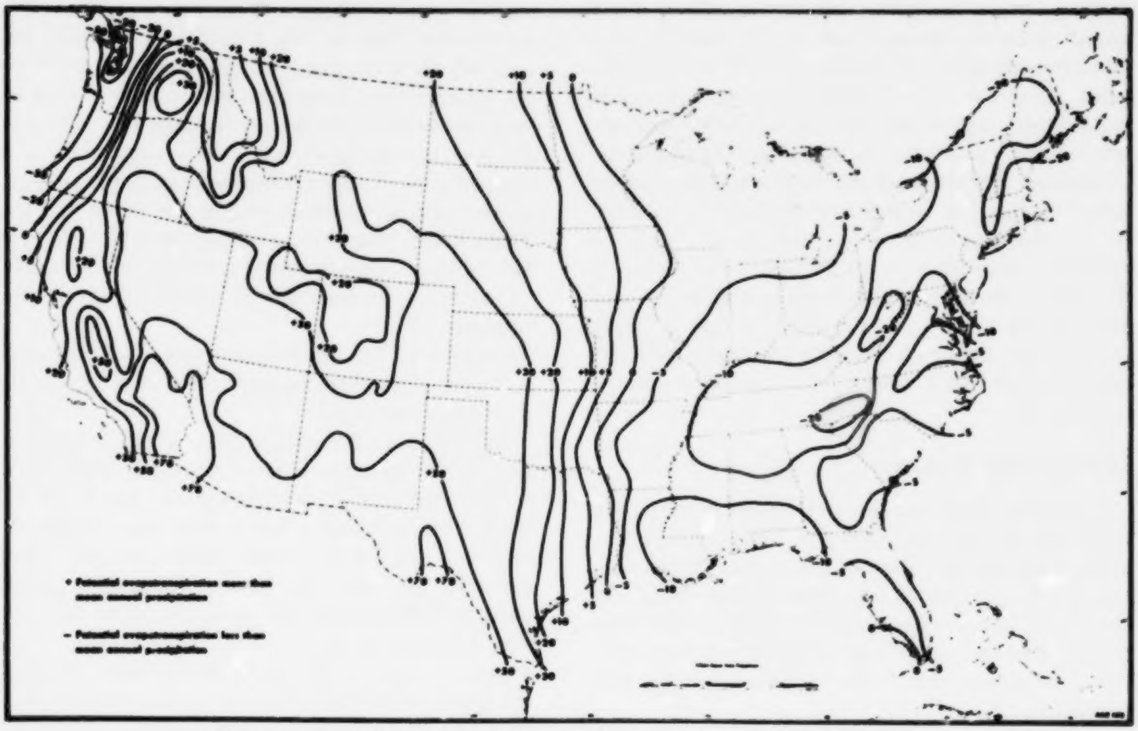

Figure 1: Potential Evapotranspiration vs. Mean Annual Precipitation (Inches).

of precipitation throughout the year. Even in the humid part of the country there is usually a moisture deficit during part of the summer; there may be a large excess of moisture during the winter in arid parts of the country. Variations from year to year must also be considered. A system that may work well in an average year may be seriously overloaded during an exceptionally wet year. Figure 2 shows the frequency distribution for precipitation deficits for six weather stations of the Midwest. The histograms are rather flat, and the range between the effectively driest five percent and the wettest five percent of the years is between 30 and 55 inches. This range of 55 inches is in the same order of magnitude as that for the mean annual values for approximately 80 percent of the country. The disadvantages of erratic precipitation can partly be compensated by proper system design and by restricting disposal sites to the most favorable soils.

Geologic Factors

The discussion so far has been restricted to individual disposal sites and a soil mantle of six feet or so. For most intensive disposal systems the nature of the underlying rock must be considered. If the rock is an unconsolidated soillike material, it may add to the ability of the soil to absorb and filter. Hard rock un-

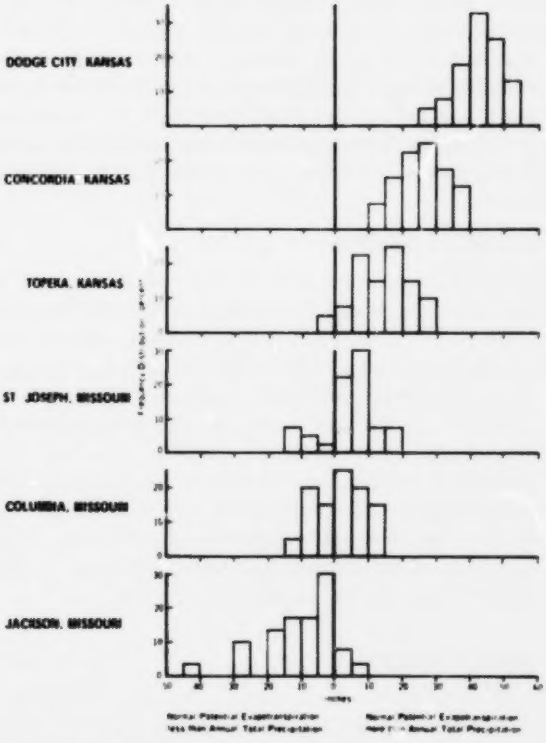

Figure 2: Frequency Distribution. (Normal Potential Evapotranspiration vs. Annual Total Precipitation.)

derlying the soil at shallow depths, particularly if it is jointed as certain igneous rocks or if it contains solution channels such as limestone, may detract from the value of a soil as a disposal medium. Regional groundwater regimes and the capacity of the groundwater system to accept the added load must also be considered. Soil drainage characteristics and groundwater regimes can be modified through the installation of drainage systems, but such systems must be carefully designed not to detract from the ability of the soil to destroy and absorb pollutants. In the arid part of the country, the possiblity that a rising groundwater level may bring dissolved salts from underlying beds within reach of the vegetation must be considered.

Institutional Factors

In general, soils that are well suited as media for waste disposal are also desirable for agricultural or urban development. They may be intensively farmed, and if they are located near metropolitan areas, the farms may be relatively small. Hence the cost of purchasing the land or making arrangements with individual farmers to use sewage effluents or sludge may be difficult.

Institutional arrangements will be simplest in those parts of the United States where irrigation is practiced and where effluents provide a source of irrigation water that is not otherwise economically available. Major metropolitan areas in the Southwest have large acreages of land that are publicly owned or land in large holdings that are now extensively used. The availability of such land in the East is limited.

CONCLUSIONS

Soil surveys conducted by the Soil Conservation Service and its cooperators indicate that soils that are suitable for land-based waste disposal systems are available near most metropolitan centers of the country. Such suitable soils may, however, cover only a small part of the total landscape in a given area and considerable care must be taken in locating and evaluating suitable sites. Climatic and institutional factors suggest that land-based disposal systems are likely to be ecologically safer and economically more attractive in the semiarid and arid western part of the country than in the humid eastern part.

DISCUSSION

QUESTION: Belford L. Seabrook, EPA, Washington, D. C. You talked about sites that were suitable for land disposal. I would like to know whether you considered the other three types of land application. That is crop irrigation, infiltration and overland flow or spray run off, which are definitely not land disposal. Disposal seems to make everybody mad and seems to connote something that is bad, so did you include those and if so, it seems you have selected a lot of places where you say that land application such as overland flow is not suitable. Paris, Texas is one of the best examples of this, where you have a dense clay soil and yet, they have been applying water by overland flow for many years, very successfully.

ANSWER: The limitations I discussed were general limitations assuming infiltration of water and the wastes into the soils.

COMMENT: Bob Dean, EPA. There is one area that Mr. Klaus seems to have left out, in fact most of us have left out in our discussions, and I see Jim Evans over here representing that area, namely the forests. I am not as worried about the food chain when we go into the forests which are greatly nitrogen deficient. Certain trees, not all of them, are very tolerant of metals. They learn to live in the mountains where often the metals are there. We have minimum interference with the public health aspects because there is much less public access and in plantations there is virtually no public access. They keep you out. The deer hunter won't go more than about three miles into the forest from a road no matter how many deer there are further in. This was demonstrated in New York State very clearly. We are not looking at the cut over land that was forest, we tried to crop, we failed, we went west, it surrounds our cities, some people call it deer pasture, scrub, you have lots of names for it. It is abundant area. It is ruled out because you wrote it out universally because you said it was all too steep, and have you even seen sludge flowing down over a forested slope and seen how well it is caught in the forest litter. It doesn't reach the bottom of the hill. There are a lot of things we can look at, but sitting back in a little ivory tower as we said, well, it is going to get into the food chain, we mustn't put it on the land. Well, there is a lot more land than that which is used for agriculture and a lot of that would benefit greatly by applications of nitrogen.

CHAIRMAN: Darwin Wright, EPA. Do you want to respond to that?

ANSWER: Klaus W. Flach, USDA. This is quite correct, but most land that are in forest are there for a reason and the reason is because the land is steep and the sludge may not run down the hill but the run-off water will. A lot of the soils in forest are shallow. There is rock under it and water will move through that shallow soil and move into aquifers. So there is very definitely a potential.

Secondly, for pollution and thirdly, many of our metropolitan areas are not near large areas of cut over forest land. Some are and many are not.

QUESTION: Ken Dotson, EPA, Ohio. Was your criteria for rating soils primarily based on the sewerage effluent or the sludge? And to follow it up a little bit, it appears to me to have been primarily based on effluent because of the effluent is a problem of water whereas the sludge is primarily a problem of solids. Is that correct?

ANSWER: That part of the paper I presented was primarily directed towards effluents. The limitations for a soil for sludge disposal would be less as far as the water holding capacity of the soil would be concerned. On the other hand, if you do want to grow a crop on your sludge disposal site you have to have the ability to hold water to grow a crop without artificial irrigation.

Soil-Plant Relationships (Some Practical Considerations In Waste Management)

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ABSTRACT

Soil-plant relationships that may influence municipal sludge and effluent applications on land are discussed. Among these are nutrient mobility in the soil, ion absorption by plants, methods of determining plant composition through soil analysis, importance of sludge placement to ion absorption by crops and nutrient absorption through foliar feeding. Distinction is made between recycling and disposal of wastes on land. Several management factors in waste disposal on land are evaluated. Monitoring problems, especially as related to soil or plant analysis, are discussed with plant analysis rated more practical at this time. Normal plant composition ranges and suggested tolerance levels for toxic heavy metals are given. Research recommendations meriting high priorities include (1) defining the available form of heavy metals, (2) correlation studies between soil levels and plant composition, (3) absorption of noxious compounds from foliar spray irrigation, (4) determination of residual nutrient levels in "living filter systems" of effluent treatment, (5) determination of tolerance levels of toxic heavy metals permissible in feeds and foods and (6) determining disposal management systems that maximize the beneficial properties while minimizing the hazards from applying municipal sludges and effluents on land. Additional Index Words: Soil-plant relationships, toxic levels in plants, waste disposal on land.

INTRODUCTION

In nature the soil is the medium which physically supports and nutritionally feeds the plant. The characteristics of the soil, both physical and chemical, can have a significant affect on the plant. The purpose of this paper is to call attention to some of the well established soil-plant relationships as they may influence the use, the choice of the area and the expected results from applying municipal sludges and effluents on farm land.

Municipal wastes contain all of the nutrient elements essential for plant growth. The essential elements that plants obtain from the soil are N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, B, and Mo with Se, V, Cl, Na and Si possibly required for some crops. These are chemical elements without which the plant cannot complete its life cycle. In addition, I, Co and F are essential or beneficial to animals. Other elements like Ni, Cd, Cr, Hg, Se, As, etc., also are present in many municipal sludges and effluents and may be considered as contaminants to the soil-plant-animal-human food chain. Therefore, the application of municipal sludges and effluents on land may be considered a recycling process for the essential nutrients and a disposal repository for all other non-essential components. The primary consideration, then, becomes management such that *beneficial aspects are maximized and its adverse affects minimized.*

Soil-Plant Relationships

To understand the soil-plant system it is important to recognize some of the chemical properties of soils associated with plant nutrition. Almost all soils have the property of cation exchange. All soil colloids, the clay minerals and soil organic matter, are negatively

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charged and are dominantly solid polyvalent anions. Negative charged sites arise mainly from broken bonds at the surface and internal substitution groups within the lattice structure. The inorganic colloids, e.g., the clay minerals, may also have some anion exchange properties from broken bonds at the clay surface giving rise to positive charges. Because the colloids are solids, both negative and positive charge sites can exist on the same particle. The negative charge sites far outnumber the positive charge sites and a single soil colloid particle may have several hundred negative charges and carry a wide variety of charge-balancing cations. The term "cation exchange capacity" refers to the measure of the magnitude of the negative charges and is given terms of milliequivalents per 100 grams of soil. The composition of the cations on the colloid surface will be a function of the bonding energy of the cation, which in turn is determined primarily as its hydrated radii and its charge, and its concentration in the system.

In a soil system the colloid is held in place in the soil matrix. The cations adsorbed on the colloids are thereby also held in place and protected from leaching as long as the soil solution is relatively free of mobile anions.

The inorganic colloids can also, due to their positive charge sites, adsorb and hold anions on their surface. This is known as anion exchange. Anions may also be adsorbed through chemadsorption, that is, bonded through a di- or tri-valent cation held on the cation exchange complex. Some anions can be adsorbed through surface molecular adsorption. All three mechanisms are instrumental in retaining high energy anions on the soil colloid and protecting them from leaching loss.

Plant nutrients in the soil may be classified as either mobile or immobile[7]. An immobile nutrient is one that is adsorbed on the colloid surface. A mobile ion, or nutrient, is one that moves freely in and with the soil water and has essentially no attractive force, or bonding energy, toward the colloids. Among essential elements occurring in the anion form chloride, Cl^-, nitrate, NO_3^-, borate, HBO_3^{--} and sulfate, SO_4^{--}, are mobile while anions like the phosphate, HPO_4^{--} and $H_2PO_4^-$, and molybdate, MoO_4^{--}, are immobile. There is no completely mobile cation in a soil with cation exchange properties. It is the exchange capacity, and the surface adsorption reactions, in a soil that distinguish it from greenhouse gravel or solution culture systems. In hydroponic systems all ions are mobile. In a soil system all essential nutrients, except the nitrate, sulfate, borate and chloride ions are immobile. Therefore, data from nutrient culture studies in greenhouse hydroponic systems can seldom be applied or extrapolated directly to soil field conditions.

Plant roots grow and elongate at the root tip. Growth continues throughout the life span of most plants. This means that the roots forage for immobile nutrients as they extend and grow in the soil. The time interval a given root absorbs immobile nutrients from a fixed point in the soil is relatively short, three to five days, for most agronomic crops due to the fact active water and nutrient absorbing areas of the root extends only from the maturation zone to the root cap, a distance of 2-3 cm. Once the root matures to where the cortex layer forms, the epidermis cells lose most of their capacity to absorb water and nutrients. The root, then, must grow toward the immobile nutrients and absorb them from colloids contacted by the root hairs. Nutrient immobility, in part, determines the effectiveness of rates and placement practices used when soils are fertilized. Thus immobile nutrients like phosphorus, potassium or zinc, for example, placed or broadcast on the surface of a soil after a cultivated crop is established will have essentially no effect on the crop as the treatment is placed and remains outside the root feeding zone. The same is true for sludges applied to the soil surface. Sod crops and grasses, if the sludge does not cause leaf injury, can absorb some nutrients through their crown and leaves and can possibly benefit from surface applications.

A mobile nutrient like the nitrate anion moves in and with the soil water. Water can and does move faster in the soil than roots grow and virtually all of the nitrates within the root zone are available to the plant. As long as there are nitrates and water in the root feeding zone the plant grows normally with respect to nitrates. When the supply in the soil is exhausted nitrogen deficiency symptoms on a crop appear suddenly and dramatically. In contrast phosphorus deficiency symptoms will remain with the plant from the time it is a few inches tall until maturity because phosphorus is an immobile nutrient.

The relationship between the levels of immobile nutrients in the soil and plant growth and yield have been reasonably well worked out and such studies form the basis for rapid soil test calibrations and fertilizer use recommendations. Generally, these relationships[21], were expressed through an exponential or quadratic type of mathematical expression. Bray[6] has used the Mitscherlich equation, $\log(A - y) = \log A - c_1 b - cx$ where:

A = the maximum crop yield
y = yield at any given level of b or $b+x$
b = quantity of the available nutrient in the soil
x = quantity of fertilizer added
c_1, c = constants

with considerable success. Less satisfactory results[3,4], have been obtained in relating the levels of immobile nutrients in the soil to the percent mineral composition of the plant. Here the exponential form[3] has proven more successful. The common form used is: $y = A - e^{-c}\,1^{b-c\ x}$ where:

A = percent composition required for maximum yield
y = percent composition at any given level of b and x
b = quantity of the available nutrient in the soil
x = quantity of the nutrient added
c_1 and c = constants

The importance of these expressions is that they show that the percent composition, and yield, of a crop is a function of the sum of the original element level, b, and that added, x, in a sludge or fertilizer. Or stated another way, adding a fixed quantity, x, of an element to two soils having different nutrient levels, b, can produce radically different results. The reason the relationship between soil nutrient and yield are more accurately correlated, than soil nutrients and percent composition, may be due in part to the fact that once a soil nutrient drops to levels low enough to cause growth stress, or a decrease in yield, it acts more nearly as an independent variable affecting growth. At levels in the plant where growth stress does not occur considerable interaction between nutrients may take place. Thus, the interactions[20] between Zn-P, Ca-B, Cu-Al, K-Mg, etc., are but a few of the common ion-pair interactions documented in the literature. Any nutrient raised to toxic levels in a plant will affect the absorption of all other ions as growth decreases. The extent to which increasing the levels of some essential nutrient might be used to suppress absorption by plants of toxic heavy metals has not been fully studied and merits research considerations. Tolerance levels of plants to any immobile toxic element is much greater in the soil system than it is in a hydroponic system. In solution systems ion interactions are much more likely to occur because of greater ion mobility and toxicities will occur at lower levels.

Salts, and soil solution extracts high in salts, may inhibit the absorption by plants of ions like Ca, Mg, K and many of the essential heavy metals as well as create an osmotic pressure outside the root retarding the movement of water into the roots[2]. Whenever the expressed soil solution, a water culture solution, or irrigation water has an electrical conductivity in excess of 2 mmho/cm at 25°C, or an osmotic pressure in excess of 0.72 atmospheres yields of very salt-sensitive crops may be restricted. However, most agronomic crops are less sensitive to salts and yield depressions may not occur until the electrical conductivity in the expressed soil solution is over 4 mmho/cm at 25°C, or its osmotic pressure is over 1.44 atmospheres. Salts, especially those associated with wastes, are high in mobile anions as nitrates, chlorides and sulfates. Besides contributing to the salinity of the soil solution these mobile anions add greatly to the leaching loss of bases from the soil. Any anion that leaches through a soil must carry with it cations to balance its charges. Cation levels in drainage waters accompanying mobile anions are determined, not by the solution composition on entering the soil, but by the cation exchange composition of the soil at the point of departure.

Two mechanisms of nutrient uptake by plant roots are recognized, active uptake and passive entry. Active uptake is the dominant entry pathway of cations once they are adsorbed on the root exchange surface. This is a very aerobic process by which the plant can accumulate cations against nutrient gradients and by which it exercises a degree of discrimination against cations present in the biosphere. Passive entry is the major pathway for *anions*. The plant has little, or no, capacity to selectively discriminate between the anions absorbed by the roots. Diffusion is the major entry mechanism which is regulated by the plant cells and which is needed to maintain electrical neutrality with the cations actively accumulated.

In agriculture it is a common practice to spray leaves of plants, especially citrus, with dilute single salt solutions of an essential heavy metal to alleviate deficiencies in plants if the soil is deficient in that element[10,26]. Zinc, iron, copper, and manganese, usually as sulfates, and urea are most commonly used. The leaf has limited capacity to absorb nutrients supplied to it in this manner. Since the metals are immobile cations strongly adsorbed on the colloid surface and are not likely to leach down to the root feeding zone if applied as a fertilizer to the surface of the soil, foliar spraying is the only expedient method of getting small amounts of these micronutrients into the plant. The leaf has essentially no selective capacity to preferentially absorb one nutrient over another. Thus a leaf will absorb any element contained in a spray solution. Generally the efficiency of absorption of a desired nutrient is low and decreases if the spray solution contains other salts. As with the root, if a spray solution has an electrical conductivity of 4 mmho/cm at 25°C, or an osmotic pressure over 1.44 atmospheres, damage to leaves is likely to occur.

Plant leaves are quite sensitive to toxic gas fumes in the air[13]. Most plants are particularly sensitive to ozone, O_3, nitrogen mono- and di-oxides, NO and NO_2, fluorides, F_2 and HF, and sulfur dioxide, SO_2. For agronomic crops 0.3 ppm O_3 or 1 ppm of combined NO and NO_2 in air are considered detrimental to growth. The sensitivity of leaves to noxious elements in spray solutions has not been determined adequately and merits further research.

Plants differ in their capacity to absorb nutrients from the soil. Some of these differences are genetic in origin and are associated with the physical distribution, e.g., fiberous vs tap root systems, and their chemical characteristics e.g., cation exchange capacity and pH. Plants also differ in root configurations[5] and in their capacity to transport nutrients, or toxic substances, from the roots to the above-ground vegetative structures. Transport from the stem and leaves to the seed can also vary for different species. The seed is a highly specialized, reproductive structure whose mineral composition will remain fairly constant although rather large changes may take place in the vegetative tissue. Therefore, the leaf of most plants reflects environmental and nutritional changes more readily than the seed.

Application of Wastes to Land

The application of municipal sludges and effluents to land is a desirable practice both from the standpoint of recycling and reuse of plant nutrients and from the need of municipalities for adjacent disposal sites. With proper management and monitoring controls, land disposal can be a highly effective and desirable practice[1,17]. Management practices involve considerations of several soil-plant relationships, some of which will be considered in the following discussion.

Objectives and philosophies regarding applications of municipal sludges and effluents on land will vary with location, soil characteristics at application sites and individual evaluations of environmental impacts. Thus the use of abandoned strip mine areas for *waste disposal* differs materially from recycling on actively productive crop land. In the case of strip mine sites the objective is primarily the *disposal of the waste* with land reclamation and nutrient recycling secondary objectives. The purpose of the reclamation is usually to produce a vegetative cover to lessen soil erosion and acid mine water drainage. Projected uses of the land are usually undefined and probably involve some form of industrial, recreational or residential use, not food production. Under such conditions the food quality of the vegetation except as it may affect wildlife on the disposal site, is given minor importance and high concentrations of toxic metals, up to where they start to impede plant growth, can be tolerated.

Where municipal sludges and effluents are applied to productive farm land, the primary objective becomes their use as a source of plant nutrients for maximum crop production. Since all good farm land is well drained, the rate of waste application must be a balance between an amount that supplies adequate levels of nutrients, usually set by their nitrogen and phosphorus content, and the probable loss of nitrogen, either through runoff or leaching, adding to groundwater contamination. Only through surface runoff and erosion can appreciable quantities of immobile ions be lost from the soil. Management practices can be directed toward minimizing both the leaching and runoff losses and the actual uptake of noxious compounds by the crop. Under normal conditions crops are very low in toxic heavy metals and from an environmental point of view it is desirable to keep contaminants out of the food chain. Many of the toxic heavy metals are immobile and can remain in the soil for many years. As a temporary safe expediency for the disposal of municipal sludges and effluents the heavy metals may be increased in the soil and plants without doing permanent damage to either. But it is unrealistic to think of good farm soil as a continual disposal area for the industrial toxic heavy metal wastes now incorporated into the metropolitan sanitary sludges and effluents. It should be remembered that municipal sludges and effluents containing non-essential noxious chemical compounds cannot be expected to enhance the soil for crop production but rather that they will not deleteriously affect, under controlled applications, the soil to where crop yields and quality are impaired. After noxious contaminants are removed from sanitary wastes, sludges can become a valuable fertilizer for crops and its disposal on land should be encouraged.

Farm soil is usually plowed and cultivated to a depth of six to eight inches. Therefore, municipal sludges and effluents applied to such land will essentially be incorporated into the surface plow depth. Since all toxic heavy metals are immobile in the soil, plant roots, after they penetrate the soil below the plow depth, will be feeding in uncontaminated areas. This means that early harvested hay crops whose growth occurred while most of the roots were feeding in the surface plow layer would have a relatively higher content of any added toxic metals than the later growth, as for example the first cutting of a legume versus the second or third cutting. Similarly, corn and soybean grain would contain relatively lower toxic nutrient levels than the stover and straw because a bigger proportion of the roots are now in the deeper untreated soil. In contrast, if the sludge were applied to the 12 to 18 inch depth, the heavy metal content of the early growth would be relatively lower than later growth. Thus placement of sludge, like fertilizers, can greatly influence the heavy metal composition of different portions of the crop. The more uniformly the treatment can be mixed into the soil the smaller will be the relative proportion of any element absorbed because plant roots contact only a very small portion of the total colloid surface area. If the sludge is applied to the soil surface with no mixing, or cultivation, then only a very small proportion of the immobile elements will find their way into the crop.

The use of land, or sandy soils with considerable permeability and some cation exchange capacity, as a tertiary water treatment facility for sanitary effluents present problems that need careful evaluation. The system requires soils with two basic properties, permeability and adsorption capacity, to remove ions from the water, but these tend to counteract each other. The system may be likened to a water softener where the entering water high in calcium and magnesium exchanges these ions for sodium ions held on the softener's exchange material. In the field, often referred to as the living filter system, the surface sand will adsorb the noxious compounds from the water and replace them with whatever ions are attached to the subsoil sand at the point where the water leaves the filter system. The higher the exchange capacity of the sand the greater its purification ability. But increasing exchange capacity means increased clay content and decreased water permeability[9,12]. Therefore, one aspect of site selection is the balance between soil permeability and ion adsorption capacity. A sand, or gravel, field devoid of clay particles and exchange properties would simply be a large scale hydroponic system. A productive silt loam soil with high ion adsorption capacity would have an infiltration rate too low to operate successfully as a filter system.

When a salt solution is passed through a soil an equilibrium is established between the cations on the soil colloids and those in the leaching solution. The resulting equilibrium established in the soil is a function of the composition and concentration of the salts in the effluent solution and the cation composition of the colloids[22]. It is unlikely this equilibrium will produce a cation composition in the surface of a sandy soil that is ideal for high crop production. While such equilibria can be calculated for the common essential nutrients whose bonding energies are known, the bonding energies precipitate formations and the general soil reactions of many of the toxic heavy metals are not known and their relative total adsorption is difficult to determine. Research in this area is urgently needed.

Anion adsorption from the effluent water must also take place. Phosphate anions will dominate the suite of immobile anions with smaller amounts of chromate, arsenate, borate, molybdate, selenate and the many other anions present in smaller amounts. In sandy soil it is unlikely the anion exchange adsorption capacity will be sufficient to extract all immobile anions from the effluent. Purification, or removal, will depend on their being precipitated from the solution. The most likely precipitant, or absorbing agents, will be lime and iron and aluminum gels that the sands may contain. Sulfate, borate and chloride anions will move through the sand, except for the small amount that may be absorbed by the crop.

Removal of the mobile nitrate anion will require a living crop on the sand whose root system can absorb nitrates from the effluent water as it leaches downward. The efficiency with which roots can absorb nitrates from the moving effluent solution will depend on climate, soil and air temperatures, nitrogen needs of the crop, nature and distribution of the crop's root system, maturity stage of the crop and the downward flow rate of the solution. This is an area where considerable research is required and should include, among other things, the following:

1. Determination of the residual level of nitrates various crops will leave in a flow solution culture system.
2. Determination of the influence of various flow rates on all nutrient absorption by crops.
3. Determination of the minimum root density required for effective nitrate removal.
4. Determination of the effect of various seasonal factors, especially temperature and sunlight, on nitrate absorption from leaching solutions, e.g., are nitrates absorbed at night?

Tertiary treatment of effluents with living land filter systems usually envisions an overhead irrigation system operating daily throughout the crop-growing season. While overhead irrigation systems have been used in agriculture for years, sometimes using fairly salty water, intense daily irrigation with effluents containing many noxious compounds and toxic heavy metals have not been studied, especially as relates to toxic metals absorption through the leaf surfaces. This is an area that requires intensive research which might include the following:

1. Determine the repression, if any, from daily spraying of leaves with effluents containing noxious compounds.
2. Determine the amount of toxic heavy metals, like Ni, Cd, Cr, Pb, etc., absorbed through the leaves under continuous spray regimes, that various crops can tolerate. Are toxic heavy metals more harmful when absorbed through the leaf surfaces?
3. What is the salt tolerance of various crops under continuous overhead irrigation as compared to soil irrigation?

Monitoring Disposal Systems

Monitoring the effects of applying municipal sludges and effluents on the soil and on the resulting vegetation is a necessary follow-up of such practices. Two approaches are possible, or they can be used together. One is systematic soil analysis and the other is plant analysis. Both have limitations that could be resolved with research and each has desirable characteristics under given conditions. A brief discussion of each follows.

Soils differ widely from region to region. From the standpoint of monitoring such differences in soil characteristics as clay type and amount, pH and carbonates, and soil organic matter can influence the stability of the available plant forms and hence the nature of the chemical reagent required to extract the element from the soil. Thus manganese, aluminum, iron and most of the heavy metal cations as well as phosphate, molybdate and many of the toxic anion forms are examples of ions whose stability vary greatly with changes in pH and organic matter[24]. From past experience, and the inability to establish uniform soil testing methods for the determination of available essential heavy metals like zinc and copper under a wide range of soil conditions, the likelihood of developing standard methods of analyses for the toxic elements are rather remote. Analytical methods for determining the total quantity, and in some cases the available form of some toxic heavy metals in soils are available for some regions. But as indicated earlier, the toxic heavy metals in the soil or added in sludges and effluents must be in a form that plants can absorb to impair crop quality. If the available forms are known, soil test procedures can be developed to determine their quantity both in the soil and in the waste materials. Methods of analysis for available essential metals are well developed for different soil regions. These methods can be expanded to cover the toxic range as well as the deficiency range for which they were established. In contrast, considerable research is required to establish the available forms for many of the toxic metals and to develop testing methods for these forms before soil analyses can become an effective monitoring tool.

The objectives of the monitoring and the soil analysis are to prevent the buildup of noxious compounds in the soil to the point drainage waters become contaminated, permanent damage is done to the quality of food, feed or fiber crops, or accumulations reach levels that are directly toxic to plants. This becomes a special hazard when the land is used for disposal rather than recycling of wastes. Soil analyses require that the analytical values be correlated to plant composition in such a way that accurate and dependable predictions of plant compositions can be made. At this stage of development[1,4,6] such correlations are not reliably developed and much research is needed.

Plant analysis, at the present time, probably offers the most logical nation-wide approach possible to the monitoring problem. The plant is the final arbitrator of the impact of the treatments and their reactions in the soil as they affect crop quality. Such factors as nutrient mobility, nutrient solubility, placement and use of entry into the plant, both through the roots and leaves, and translocation within the plant are all reflected in the final plant composition. Standard analytical methods for plant analyses are available and uniformly applicable on a national scale.

Plant analysis, to be an effective monitoring tool, requires that normal composition and upper tolerance levels be known and set for the indicator plant. The average range in composition for many crops[8,11,14,15,16,18,19,23,25,27] grown under various soil and climatic conditions have been published. What is less well known, and on which differences of opinions will undoubtedly exist, are the permissible upper tolerance levels for toxic substances in plants that represent complete safety with respect to the food chain and to all future foreseeable uses of the land. The values given in Table 1 are presented to this workshop conference for the purpose of discussion and to record the authors judgment with respect to tolerance levels acceptable for some of the common feed and food crops if they are used for monitoring purposes. It cannot be overemphasized that these tolerance values are the author's and are not specifically documented in the literature. Land producing crops that normally contain nutrient levels above the tolerance level should be carefully evaluated before being used for waste disposal. The tolerance levels presented here are, by most standards, conservative.

The data in Table 1 needs considerable explanation. First, the chemical form most readily absorbed by plants is given in the column headed "probable available form". For many of the cations and anions the available form, or form absorbed by crops is well established. For some of the anions the available chemical form in soil is not well established. For example, most data tend to show that the chromate anion is more available than the chromous or chromic cations, and that the selenate anion is more available than the selenite anion or the selenium cation forms. A knowledge of the chemical forms preferentially absorbed from the soil by plants is of crucial importance to a soil analysis program and to evaluating harmful contaminations. This is an area requiring considerable research.

Plant analyses will require that a specific portion of the plant, harvested at a specific stage of development be used for monitoring purposes. Many of the

TABLE 1
The Probable Available Form, the Average Composition Range for Selected Agronomic Crops, and the Authors Suggested Tolerance Level of Heavy Metals In Agronomic Crops When Used for Monitoring Purposes.

	Probable Available Form	*Common Average Composition Range* ppm*	*Suggested Tolerance Level** ppm*
		Cations	
Barium	Ba^{++}	10-100	200
Cadmium	Cd^{++}	0.05-0.20	3
Cobalt	Co^{++}	0.01-0.30	5
Copper	Cu^{++}	3-40	150
Iron	Fe^{++}	20-300	750
Manganese	Mn^{++}	15-150	300
Mercury	Hg^{++}	0.001-0.01	0.04
Lithium	Li^{++}	0.2-1.0	5
Nickel	Ni^{++}	0.1-1.0	3
Lead	Pb^{++}	0.1-5.0	10
Strontium	Sr^{++}	10-30	50
Zinc	Zn^{++}	15-150	300

	Probable Available Form	*Common Average Composition Range* ppm*	*Suggested Tolerance Level** ppm*
		Anions	
Arsenic	AsO_4^{--}	0.01-1.0	2
Boron	HBO_3^{--}	7-75	150
Chromium	CrO_4^{--}	0.1-0.5	2
Fluorine	F^-	1-5	10
Iodine	I^-	0.1-0.5	1
Molybdenum	MoO_4^{--}	0.2-1.0	3
Selenium	SeO_4^{--}	0.05-2.0	3
Vanadium	VO_3^-	0.1-1.0	2

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* Average values for corn, soybeans, alfalfa, red clover, wheat, oats, barley and grasses grown under normal soil conditions. Greenhouse, both soil and solution, values omitted.

* * Values are for corn leaves at or opposite and below ear level at tassel stage, soybeans - the youngest mature leaves and petioles on the plant after first pod formation, legumes - upper stem cuttings in early flower stage, cerals - the whole plants at boot stage, and grasses - whole plants at early hay cutting stage.

common agronomic crops are quite similar in their average range of nutrient content, including toxic metals, when grown under similar conditions and harvested at specified stages of development. The average common composition ranges were calculated from composition data reported in the literature for crops grown on normal soils. The following crops, corn, soybeans, legumes (mostly alfalfa and red clover), cereals (wheat, oats and barley), and grasses (miscellaneous) are included in the averages. In as far as possible the composition data apply to the following plant parts and designated stages of development:

Corn - leaf at, or opposite and below, ear level at tassel stage.

Soybeans - the youngest mature leaves and petioles on plant after first pod formation.

Legumes - upper stem cuttings in early flower stage.

Cereals - the whole plant at the boot stage.

Grasses - whole plants at early hay cutting stage.

Generally, the upper common range level is that found on soils tending to be high in that element. Thus, for example, the upper selenium values are high for Illinois but fairly common for grasses in some sections of South Dakota. The suggested crop sampling stages are easy to identify in the field and hence lend themselves to more reliable monitoring.

The permissible tolerance levels suggested in Table 1 for agronomic crops assumes the following:

1. That the same tolerance levels can be used for the common agronomic crops.
2. That the above designated plant part and stage of development will be used.
3. That the municipal sludges and effluents are being recycled, or used as a fertilizer. This implies a rate of application commensurate with crop needs.
4. That the land is productive agricultural land to be used for crop production for generations to come.
5. That many of the noxious compounds in the wastes become immobile when added to the soil and will remain there indefinitely.
6. That the crop will probably absorb a part of any toxic heavy metal or noxious compound added to the soil.
7. That the tolerance level includes an acceptable safety factor. Therefore, the suggested levels are only one-half, or less, of the values the literature suggests as being:
   a. Toxic levels for animals.
   b. Plant levels at which appreciable transfer of the element from the vegetative portion of the plant to the grain occurs.
   c. The level known to be toxic to the plant itself.

Again, it is emphasized that these tolerance levels, Table 1, are *judgment* values at this time presented for discussion purposes at this workshop conference. Others may feel that these values are too high or too low depending on the ultimate use of the crops and their dilution with feeds or foods from untreated areas, or in their evaluation of the hazard of such levels in the food chain. The lack of more definite data does suggest, however, the need for research in this area. Among the many research needs are:

1. Establishment of more definite toxicity levels for heavy metals and noxious compounds in feeds and food for animal and human consumption.
2. Establish the efficiency with which crops can absorb toxic elements from an agricultural soil.
3. Establish the chemical forms noxious compounds must be in for plants to absorb them from the soil.

Sanitary wastes, free of noxious compounds, are an excellent source of many nutrients required for plant growth. Because most of the toxic elements found in municipal sludges or effluents are immobile when added to the land, appreciable quantities can be incorporated into the soil without any significant detriment to crop quality. Considerable technical upgrading of existing sanitary waste treatment facilities and recovery techniques for point source contaminants will be required before municipal sludges and effluents are free of toxic or noxious compounds. While such technical upgrading is taking place, recycling of municipal sludges and effluents on appropriately chosen farm land under good management practices should present no hazard to the soil or decrease in the quality of farm crops. Controlled land applications of wastes free of noxious compounds can be highly desirable and should be encouraged.

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Crop and Food Chain Effects of Toxic Elements In Sludges and Effluents

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ABSTRACT

Sewage sludge and effluent are applied to soil with the intent that toxic elements be retained by the soil. These elements will accumulate and persist, and are the long term environmental hazard in land application. Elements in sludge and effluent that are potential hazards to plants or food chain are: B, Cd, Co, Cr, Cu, Hg, Ni, Pb, and Zn. The direct toxicities to plants from Zn, Cu, and Ni are discussed in detail. Hazard to the food chain from Cd, Cu, Zn, Pb, and Hg in crops grown on sludge- and effluent-treated soils is discussed, with emphasis on the controllable hazard from Cd. Crop differences in injury from, and accumulation of Cd, Cu, Zn, and Ni are discussed in relation to the high phosphate and organic matter contents of sludge and effluent. Interim recommendations are made for permissible levels of toxic metals added to agricultural soils. Research needs to protect plants and the food chain are presented.

INTRODUCTION

Toxic heavy metals are the long-term hazard in land application of sewage sludges and effluents. Although I will discuss how we can manage soils and crops to minimize the possibility of injury to crops and the food chain, I do not support sludge or effluent applications which will apply metals in excess of that which allows continued general agricultural use of the land involved. We must consider toxic metal information in choosing any scheme for land application of sewage sludge and effluent.

The toxic metal considerations apply to the three general land application philosophies: (1) Use low metal sludges as fertilizer (N, P, Zn, Cu); (2) use low metal compost as a soil conditioner because of its organic matter, organic N, and P contents; and (3) use land as a repository for toxic metals to prevent pollution of air and water, and manage so as to prevent injury to food chain. In each case, the system design includes holding all toxic metals in the soil. The metals are added in large to extreme excess of crop removal, and will be affected by agricultural management practices long after they are added. Even though we can manage land application sites to control short- and long-term hazards from N, organic matter, and pathogens, the toxic heavy metals will accumulate and/or persist, thus becoming *the* long-term hazard to the environment.

Sources of Toxic Elements

Many materials added to soils may contain toxic heavy metals. Sewage sludge contains Zn, Cu, Ni, and Cd in excess of soil levels (Table 1). Sewage effluent contains Zn, Cu, and Cd, and has led to soil accumulation of toxic elements. Municipal refuse, raw or composted, contains Zn, Cu, and B. Animal manures can contain sewage sludge levels of Cu and Zn if these elements are added to feeds at growth stimulant levels much higher than that required to correct Cu or Zn deficiency for the animals. Even chemical fertilizers may contain high levels of Cd from the phosphate rock used to make superphosphate[41]. Some commericial fertilizers contain sewage sludge as an organic N source or as a cheap bulking agent. The discussion in this paper will deal with all aspects of toxic heavy metals added to soils and plants, with emphasis on sewage sludge and effluent which contains high levels of phosphate.

TABLE 1
Range of Metal Contents In Digested Sewage Sludge

Element	*Observed Range*
Zn	500-50,000 ppm
Cu	250-17,000 ppm
Ni	25-8,000 ppm
Cd	5-2,000 ppm
Cd	0.1-40% of Zn
B	15-1,000 ppm
Pb	100-10,000 ppm
Hg	<1-10 ppm

What Elements Should Be Considered?

Any element can be toxic if it is present in a large enough amount. We must limit our concern to those elements that greatly exceed normal concentrations, or will become so through repeated application of sludge or effluent. These include B, Cd, Co, Cr, Cu, Hg, Ni, Pb, and Zn. These commonly occur in sludge and effluent, and can be toxic to the plants grown on sludge- or effluent-treated soil or to the animal that consumes these plants.

Toxicity to Plants

Chromium appears to be noninjurious because it occurs at Cr^{3+} in sludge and as such is not available to injure plants. Chromate is rapidly reduced to Cr^{3+} in soil. *Mercury* does not injure plants at the low levels added with sludge and effluent. *Cadmium* can be toxic to plants, but as explained below, this element is considered hazardous to the food chain at low levels and thus dare not reach phytotoxic levels. *Lead* can injure plants in low phosphate, acid soils. Pb added with sludge and effluent appears to be nontoxic to plants because the large amount of phosphate also present ties up the Pb and prevents injury. Sludge or effluent seldom contains *cobalt*, which is a product of specific industrial pollution. If present, Co is much like Ni in toxicity, except that it rapidly reverts into Mn oxides in the soil. *Boron* in excess can injure plants; high levels of B can occur in raw or composted refuse. Boron in effluents could become phytotoxic in soils where we are now concerned about the B content of normal irrigation water.

Zinc, copper, and *nickel* are clearly toxic to plants and commonly occur in sewage sludge and effluent. The comments below relate especially to the toxicity of Zn, Cu, and Ni to plants.

Factors Controlling Metal Toxicity to Plants

A. The amount of toxic metals present in the soil.

B. The toxic metals present. Zn, Cu, and Ni differ in their toxicity to specific plants and in specific soils. Generally, Cu is twice as toxic as zinc, and Ni is eight to ten times as toxic as N. Chumbley[11] introduced the Zn(equivalent) factor [ppm Zn(equivalent) = 1 x ppm Zn +2 x ppm Cu +8 x ppm Ni] to take into account the differences among metals. He suggested that no more than 250 ppm Zn(equivalent) be added to agricultural soils (with pH maintained >6.5).

C. The pH of the amended soil. The toxic metals are much more available pH's below 6.5-7.0. A soil toxic metal content safe at pH 7 can easily be lethal to most crops at pH 5.5. Soil pH may be more important than the amount of metal added. Further, land disposal of sludge leads to a *lowering of the soil pH* due to nitrification of the high amounts of NH_4 -N added. Liming can correct this acidity if the NH_4 is in the tillable layer of the soil. Effluent irrigation generally leads to a soil pH of 6.5-7.2 as the soil comes to equilibrium with the neutral effluent.

The effects of zinc level and soil pH on injury to chard plants are shown in Table 2. Inorganic Zn (and Cd at one percent of the added Zn) was added to a Sassafras sandy loam soil and the pH was adjusted to 5.3, 6.4, or 7.2 in the metal-amended soil. The yield reduction shows a pronounced pH effect.

D. The organic matter (O.M.) content of the amended soil. Organic matter chelates the toxic

TABLE 2
Effect of Zn Added and Soil pH On Zn Content and Yield Reduction of Chard Leaves

Added Zn	*Soil pH* 5.3	6.4	7.2
ppm	*μg Zn/g dry weight*		
1.31	210	116	12
32.7	754	237	74
65.4	1058(7)[1]	337(5)	100
131.	2763(41)	765(9)	177
262.	2692(95)	1678(22)	406(27)

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[1] Yield Reduction in parentheses (%)

metals and makes them less available to injure plants. The O.M. is especially important in binding Cu and Ni. Chelation appears to be more important than the simple cation exchange role of the O.M. At lower pH's, the O.M. reduces metal availability relative to the same soil without the O.M.; however, at high pH, the O.M. appears to increase availability, at least for Zn. The O.M. can also slow reversion of metals to unavailable forms. Because of the importance of O.M. in protecting against metal toxicity, management of O.M. is very important.

As the organic matter added with the wastes gradually decomposes[29], its protective effect is lost. Leeper[25] discussed the disappearance of O.M. added with sewage sludge and how a soil could be built up to high metals and O.M. level and remain nontoxic to plants, and yet ten years later with no further O.M. addition could become toxic as O.M. disappeared. Miller and Zaebst[30] found that sludge O.M. was no more stable than soil organic matter, and part of sludge O.M. was oxidized quite rapidly.

Crop rotation, green manuring, or other practices which maintain high O.M. should help reduce metal toxicity. Even additions of more sludge may reduce existing metal toxicities in spite of adding more metals with the O.M.[17]. Climate influences the persistence of O.M. in soil and thus indirectly affects the potential for metal toxicity.

E. The phosphate content of the amended soil. Phosphate is well known for reducing Zn availability to plants and decreasing the stunting injury caused by excessive levels of toxic metals. However, PO_4 enhances iron deficiency chlorosis caused by excess Cu and Ni[40]. Sludge and effluent will add considerable PO_4 with the metals they supply to soils. Application of 50 T/ Ac of a sludge containing four percent P adds 4000 lbs P/ Ac. This is an extremely large amount, and P buildup may become a limiting factor in sludge application for P-sensitive crops, e.g., soybeans. No published data are available to estimate the interaction of pH and PO_4 on Zn toxicity.

F. The cation exchange capacity (C.E.C.). The C.E.C. of the soil is important in binding all cations, including the toxic metal cations. This includes the C.E.C. of the O.M. (which also chelates toxic metals, see above), and of the clay colloids. A soil with high C.E.C. is inherently safer for disposal of sludge and effluent than a soil with low C.E.C.

G. Reversion to unavailable forms. The toxic metals "revert" with time to chemical forms less available to plants. Reversion has been clearly established for Zn[9] and can be quite rapid[15]. The process of reversion is poorly understood, but reversion is most rapid in calcareous soils. The soil pH, PO_4 and O.M. contents, and amount of newly added toxic metal can each affect reversion rate and extent. Cobalt reversion is related to the amount of Mn oxides in soil. No clear evidence is available on the reversion form of other toxic metals. Reversion of some metals can be reversed by prolonged soil submergence[32], and especially by a pH decrease. On a poorly managed site, the rapid O.M. destruction and low pH may actually lead to a net increase in toxic metal availability and injury even though the pH remains unchanged.

H. The plant grown on sludge- or effluent-treated soil. Plant species vary widely in tolerance to toxic metals, and varieties within a species can vary three- to tenfold. Vegetable crops very sensitive to toxic metals are the beet family (chard, spinach, redbeet, and sugarbeet), turnip, kale, mustard, and tomatoes. Beans, cabbage, and collards, and other vegetables are less sensitive. Many general farm crops (corn, small grains, and soybeans) are moderately tolerant. Most grasses (fescue, lovegrass, Bermudagrass, orchardgrass, and perennial ryegrass) are tolerant to high amounts of metals. Highly tolerant ecotypes of the grasses are found on ore outcrops containing extremely high amounts of metals[3].

Crops vary widely in their susceptibility to different toxic elements[7,8,10,22,24,42]. The early work of Hewitt[20] with several toxic metals and recent work of Page *et al.*[33] with Cd in nutrient solution can not easily be extrapolated to soils.

Celery is known for its unusual tolerance to excess Cu[44]; however, it is as sensitive to Zn and Ni as most vegetables[43]. Metal tolerant grass ecotypes developed tolerance only to the metals in excess in the soils on which the ecotypes were growing[3]. The 1:2:8 ratio for the relative toxicity of Zn:Cu:Ni used in the Zn(equivalent) factor is only an average of the relative tolerance for many crops. The apparent relative tolerance of crops will vary in different soils depending upon the levels of O.M., PO_4, and pH which control the relative toxicity of Zn vs Cu or Ni. Crops also differ in the accumulation of metals in their leaves or edible parts.

The root is the metal-sensitive organ in plants. Excess Zn, Cu, and Ni reduce root yield more than top yield. Chlorosis caused by Zn, Cu, or

Ni is actually the result of reduced Fe transport by roots. Metal analysis of roots has been proposed to demonstrate toxic metal injury because the root prevents much of the toxic metal from reaching the leaves[14]. A synergistic toxicity, where the combined effect of Zn and Cu is worse than the sum of the injury from separate Zn and Cu treatments, probably may be reasonably estimated only from root analysis because of the effects these metals have on each other's transport to leaves. Assays for varietal difference to toxic metals invariably have shown the root to be the best indicator organ.

The root also appears to be the site of PO_4 interference with both toxic metal injury and transport. In studying toxic metals in sludge and effluent, the simultaneous presence of excess PO_4 produces a situation where little of the available literature can be meaningfully applied. PO_4 has already been mentioned as inhibiting Fe transport and interacting with Cu and Ni which also produce Fe deficiency[40].

Danger To the Food Chain from Toxic Metals

Toxic metals added to soils are not a hazard to the food chain until they have entered an edible part of a plant—leaf, grain, fruit, or edible root or tuber. Some direct ingestion of recently applied metals[4], or of soil containing large amounts of metals will be a special hazard to animals grazing sludge- or effluent-treated sites.

The elements that are a significant potential hazard to the food chain through plant accumulation are Cd, Cu, and Zn.

Very high amounts of Cr^{3+} added to soil do not increase the Cr contents of crops appreciably, and constitute no hazard. Boron, Co, and Ni at levels that severely injure the plant, present no threat to the food chain. Mercury from sludge will increase soil Hg levels, but the increase in plant Hg will be small (Tables 3, 4, 5, and 6). Hg does not appear to constitute the food-chain accumulator in agriculture that it does in the oceans. Pb is not translocated readily to plant tops, and is especially excluded from grain, fruits, and edible roots (Tables 3, 4, 5, and 6). The lack of Pb accumulation appears to be related to the presence of the high amount of PO_4 in sludge and effluent.

Underwood[41] summarized much of the available information on Zn and Cu excesses in animal nutrition. The more sensitive animals suffer from Zn toxicity if the diet contains between 500 to 1000 ppm as Zn sulfate. Plants that contain 1000 ppm Zn or more are usually severely injured, and would show economically damaging yield reductions; however, the data in Table 2 conflict with the data of Boawn & Rasmussen[8]. Because yield usually is reduced at lower plant Zn levels than those that injure the animal that consumes the plant, the food chain appears to be protected. Available information on toxicity to animals from Zn in food crops is insufficient to establish a safe plant Zn level.

Cadmium is somewhat like Zn in that increases in soil Cd from sludge or effluent can lead to increased food chain Cd. The Food and Drug Administration expects to eventually specify the permissible level of Cd in foods in the marketplace. The only apparent way to be sure that the Cd in a food crop grown on a sludge- or effluent-treated soil will not be a potential food-chain hazard is to reduce the Cd content of sludges to 0.5 percent of the Zn content, and as near as possible to 0.1 percent of the Zn content (Table 7).

TABLE 3
Effect of Sludge On Toxic Elements In Corn[1]

Element	*Soil Available*[2]		*Corn Leaves*		*Corn Grain*	
			Tons Sludge/A[3]			
	0	*44*	*0*	*44*	*0*	*44*
Cd, ppm	0.22	7.0	3.3	11.6	0.30	1.03
Zn, ppm	13.	181.	58.	212.	89.	152.
Cd/Zn, %	1.7	3.9	5.7	5.5	.34	.68
Cu, ppm	3.9	32.	8.9	8.7	5.2	5.6
Ni, ppm	2.3	7.0	2.8	4.3	2.3	3.1
Pb, ppm	6.6	30.	7.1	6.3	.025	.028
Hg, ppb	44.	273.	27.	38.	5.2	3.6

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[1] Data of Hinesly, Jones, and Ziegler[21]

[2] 0.1 N HCl extractable, April 1971.

[3] April 1970.

TABLE 4
Effect of Sludge On Toxic Elements In Corn[1]

Element	*Soil Content*		*Corn leaves* *Tons sludge[2]/A.7"*		*Corn grain*	
	0	*182*	*0*	*182*	*0*	*182*
Cd, ppm	2.4	98.7	0.8	11.7	.07	.29
Zn, ppm	69.	1679.	36.	232.	20.	31.
Cd/Zn %	3.5	5.9	2.2	5.0	.35	.93
Cu, ppm	20.	483.	16.	16.	6.	6.
Ni, ppm	40.	115.	3.8	4.0	2.0	2.7
Pb, ppm	36.	361.	7.0	3.5	1.5	0.44
Hg, ppb	10.	1392.	19.8	26.0	2.0	2.4

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[1] Data of W. J. Bauer[4].

[2] Chicago-WSW lagooned digested sludge: SEMCO.

TABLE 5
Effect of Sludge On Toxic Elements In Soybeans[1]

Element	*Soil Content*		*Soybean Leaves*		*Soybean Grain*	
			Ton sludge[2]/A.7"			
	0	*103*	*0*	*103*	*0*	*103*
Cd, ppm	3.0	50.	0.6	5.1	.37	2.0
Zn, ppm	91.	873.	38.	165.	43.	114.
Cd/Zn, %	3.30	5.73	1.58	3.09	0.86	1.75
Cu, ppm	25.	229	15	18	16	20
Ni, ppm	50.	96	8	13	5.7	13.
Pb, ppm	38	200	4.5	4.0	2.0	1.8
Hg, ppb	11	977	62.	28	2.8	3.2

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[1] Data of W. J. Bauer[4].

[2] Chicago WSW lagooned digested sludge: SEMCO.

TABLE 6
Effect of Sludge On Toxic Elements In Fodder Rape[1]

Element	*Soil Content*		*Fodder Rape*	
	Control	*Sludge[2]*	*Control*	*Sludge[2]*
Cd, ppm	1.2	1.7	0.6	0.6
Zn, ppm	98.	369.	34.	114.
Cd/Zn, %	1.2	0.46	1.8	0.52
Cu, ppm	26.	90.	3.9	8.3
Ni, ppm	28.	43.	4.9	9.2
Pb, ppm	26.	44.	5.2	7.7
Hg, ppb	18	675	33.	49.

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[1] Data of Anderson and Nilsson[2].

[2] Eight applications of 3.12 T/A every second year = 25 T/A.

TABLE 7
Cadmium and Zinc In Soils Versus Crops

Soil *Cd:Zn*	*Leaf Crops[1]* *Cd:Zn*	*Grain, Fruit Root Crops[1,2,3]* *Cd:Zn*
%	ppm	ppm
8	40:500	3.2:200
1	5:500	0.4:200
0.5	2.5:500	0.2:200
0.1	0.5:500	0.04:200

---

[1] Ratio in crops could double if soil at pH >7.

[2] Ratio is 3-10 times lower than ratio in leaves.

[3] Commercial Zn metal contains .04% Cd.

In this way, Zn excess (at about 500 ppm Zn in leaves) would injure the crop before the Zn or Cd content of the crop constituted a health hazard. Zn appears to compete with Cd at the sites of uptake and injury in animals, and the high Zn in crops grown on sludge- and effluent-treated soil should serve to prevent Cd injury. Many questions remain about what levels of Cd vs Zn, absolute Cd level, etc., in crops are safe for the human food chain. Controversy will remain until experiments clarify the Cd and Zn relationships in natural food diets *vs* injury to animals throughout their lifespan. The concept of Cd:Zn ratio obviously is very important in evaluating the agricultural movement of Cd into the food chain.

Copper will cause severe plant injury before the content is high enough to be toxic to most animals. However, sheep are very sensitive to plant Cu, and some forages grown on soils enriched in Cu by sludge or effluent could be toxic to sheep. When sludge is sprayed on pastures, Cu is a special hazard (along with Pb) until rain washes the Cu from the leaf surfaces.

Factors Affecting Plant Accumulation of Toxic Metals

A. Any factor that affects the availability of the toxic elements in the soil also affects the plant accumulation. Thus, total amount of metal, pH, O.M., PO_4, C.E.C., and reversion control the amount of excess metal available to the root. For example, the effect of pH is seen in Zn and Cd accumulation by crops (Tables 8 and 9). Many experiments with excess metals have failed to include pH variables, so our knowledge of pH effect on metal accumulation is clearly insufficient. Organic matter may simultaneously lower injury and increase accumulation because low molecular weight chelates of Cu and Ni are formed, which protect the root from severe injury and stunting.

TABLE 8
Effect of Sludge Cd and Zn On Cd:Zn Ratio In Corn[1]

Sludge Rate[2] T/A	*Soil[3]*	*Cd:Zn Ratio Leaves Cd/Zn, %*	*Grain*	*Grain Leaves %*
0	1.7	5.7	0.34	6
11	3.7	3.5	0.65	18
22	3.9	3.8	0.62	16
44.1	3.9	5.5	0.68	12

[1] Data of Hinesly, Jones and Ziegler[21]

[2] April 1970. [3] 0.1 N HCl extractable, Apr. 1971.

B. Characteristics of the toxic metal. In acid soils, the elements Zn, Cd, and Mn are easily translocated to plant tops. In strong contrast, Cu, Ni, Pb, and Hg are translocated in appreciable quantities only during severe injury to the plant. Compare the results of Boawn and Rasmussen[8] for Zn with the results of Roth *et al.*[39] for Cu and Ni, and the results of Baumhardt and Welch[6] for Pb. Zn reaches >1000 ppm, whereas Ni and Cu seldom exceed 70 ppm, and Pb is even less.

C. Presence of competing ions. Cd and Zn competition was observed in the studies of Zn transport by Hawf and Schmid[19]. Some evidence of possible effects of sludge Cu on sludge Zn transport by several crops is shown in Table 10. The lower Zn content of leaves at low pH (5.5-6.0) than at high pH (6.5-7.0) suggests that other toxic metals can interfere with Zn transport.

D. Phosphate availability. Because PO_4 is such an important competing ion, it must be dealt with separately. A great body of data is available on the interference of PO_4 with Zn, Cu, and Fe metabolism of plants at deficient or marginal levels of Zn, Cu, or Fe availability. Excessive PO_4 is also known to injure some plants. PO_4 further appears to decrease the stunting injury from toxic levels of Cu, Zn, and Ni. The work of Spencer[40] with Cu and P at toxic levels of Cu (although confounded by uncontrolled pH changes from the PO_4 amendment) shows that PO_4 alleviates stunting *and* increases Fe-deficiency chlorosis. The pattern should be the same for Cu and Ni. Information is insufficient on the effects of the excess PO_4 added with sludge and effluent on the toxicity and accumulation of Zn, Cu, Ni, Cd, Pb, and Hg. Data also must be obtained on the long-term effects, because both metals and PO_4 revert in the soil.

E. Rooting depth and soil distribution of metals. The literature is replete with examples of soils severely contaminated with Cu which support good orchards and vineyards because their perennial roots avoid the toxic zone. Chlorosis of citrus from excess Cu occurred only when the subsoil contained too little available Fe. When these orchard soils are plowed and annual crops planted, severe failure is often observed because roots grow into the toxic zone.

Sludge can be applied in many ways (liquid applied to surface, tilled and untilled; filter cake or sand bed sludge applied and mixed well or left in chunks in the soil; covered trenches) which lead to roots being able to avoid the toxic metal zone, at least in the short run.

TABLE 9
Effect of pH On Seedling Corn Zn Content

Soil pH	*Control*	*Treatment*[1] *131 Zn + 64 Cu*	*5% Peat*	*5% Peat + 131 Zn + 64 Cu*	*5% Sludge*
	µg Zn/g dry matter				
5.0-5.2	34	1116	-	-	880
5.4-5.6	29	916	25	251	486
6.0-6.2	22	594	22	140	318
6.4-6.6	14	231	18	149	163
7.0-7.2	12	101	13	92	144

[1] Iuka sil subsoil; Crystal Lake peat; Baltimore digested sludge; Wf 9 x 38-11 seedling corn.

TABLE 10
Effect of Digested Sewage Sludge (Five Percent)[1] On Zn Content of Several Crops at Two pH's

Crop	*Leaf Zn content ug/g dry weight* *Low pH*	*High pH*
Corn	655	295
Soybean	444	222
Tomato	628	335
Mustard	1500	660
Sugarbeet	1369	1193
Chard	1270	1330
Rye	228	296
Wheat	194	272
Fescue	260	301

[1] Five percent Baltimore digested sewage sludge added 186 ppm Zn and 66 ppm Cu to Evesboro loamy sand soil.

F. Plant age and seasonal effects. The age of a leaf affects its Zn and Cd contents, and probably its Cu, Ni, Pb, and Hg contents. As shown in Tables 11 and 12, the oldest leaves of plants supplied toxic levels of Zn contained much more Zn than the youngest leaves. The growth rate of some crops allows a dilution in leaf Zn and Pb as the season progresses: seedlings › ear leaves › mature stover. Crops differ widely in this behavior; monocots do not appear to concentrate Zn in older leaves as most dicots do. Chard accumulated as much as 1900 ppm Zn and 90 ppm Cu during the season with no symptom of injury. Lead accumulation in many crops shows a strong seasonal influence[31,36]. Seasonal effects on Pb accumulation by crops grown on sludge- or effluent-treated soils apparently remain unexamined. It would appear that winter pasture could be a hazard, whereas spring and summer pasture would remain low in Pb.

G. Plant species and variety; grain vs forage. Plant species and varieties differ in toxic metal accumulations. The work of Boawn[7] with Zn, Hunter and Vergnano[22] with Ni, etc., demonstrate these differences. Few reports have been published on crop differences in accumulation of toxic metals in edible portions when grown on sludge- or effluent-treated soils.

At excess levels, the grain, fruit, or edible root of many crops contains two- to tenfold lower levels of Zn than the leaves. Thus, corn grain from a sludged site could contain less toxic metals than mixed pasture or silage. Whether the relative exclusion of toxic metals by grasses would allow more nutrient removal, yet safer levels of Zn, Cd, and Pb, than growth of corn grain is unclear. A further advantage of grain crops vs leaf crops is the two- to tenfold greater exclusion of Cd relative to Zn during grain filling (Tables 3, 4, 5, and 8).

Some have suggested that we should breed varieties of crops that can tolerate and exclude undesired toxic elements. Although more tolerant varieties probably could be developed, only an effort to produce metal-tolerant perennial grasses that would exclude toxic elements seems reasonable. This would allow maintenance of an economic crop on sites dedicated to receive sludge or effluent until other economic crops will no longer tolerate the soil toxic metal levels.

H. Soil moisture, aeration, and temperature. Any of the physical factors that affect plant growth and absorption of ions will affect accumulation of toxic metals. Essentially no information is available on effects of temperature and oxygen on uptake or transport of toxic metals. These factors may also affect reversion and soil adsorption of the toxic metals.

TABLE 11
Effect of Leaf Age On Zn Content

Added Cd mg/kg	*Soil pH*	*Caline*	*Leaf Number 1st, 2nd*	*3rd, 4th*	*Younger*
			μg Cd/g dry weight		
1.31	6.4	47	52	45	50
131	5.3	4457	2817	2208	1493
131	6.4	1114	757	637	405

TABLE 12
Effect of Leaf Age On Cd Content

Added Cd mg/kg	*Soil pH*	*Caline*	*Leaf Number 1st, 2n*	*3rd, 4th*	*Younger*
			μg Cd/g dry weight		
1.31	6.3	53.3	26.7	20.8	11.3
1.31	6.4	19.7	10.4	6.7	3.3

Cadmium and Zinc in Soils, Crops, and Food Chain

As mentioned earlier, it appears that the permissible Cd content of foods in the marketplace may be established at the current natural background levels. We will have to live within these restrictions or show that they are invalid. Although there are substantial arguments against the suggested toxicity of Cd at low levels in foods[16,26], we will have to control the level of Cd in agricultural products to meet these food standards. Little or no information is available on the movement of Cd from feed grains or pasture into beefsteak; this part of the Cd cycle is still completely open. Thus, we need to quickly obtain information on Cd movement from sludge and effluent to foods.

Several studies on land application of sludge have reported the Cd and Zn contents of the crops grown. The work by Hinesly *et al.*[21], Table 3, and Bauer[5], Tables 4 and 5, used the Chicago WSW sludge, which contains high levels of Cd (six to eight percent of Zn), and should not be considered as representative of what can be expected with acceptable levels of Cd (<0.5 percent of Zn). Table 8 summarizes the Cd and Zn data of Hinesly *et al.*[21]: Cd is left behind during grain filling. Comparison of corn and soybeans suggests that exclusion of Cd during grain filling is less pronounced in soybeans than in corn. There may be varietal differences as well. Table 13 shows the effect of soil pH on Cd:Zn ratio in the previously described chard experiment.

How do we solve the Cd problem in land application of sludge and effluent? First, we can prevent sludges and effluents with a high Cd:Zn ratio (>0.5 percent) from reaching soil. Cd is generally a specific pollutant and is easily removed from wastewater to 10 μg/l at the industrial plant. I have discussed the role of Cd:Zn ratio in sludge→plant leaves→grain, fruit, or edible root movement of Cd (see Table 7). We can devise situations where sludge and effluent application will lead to a net decrease in Cd movements into the food chain, *if* the Cd:Zn ratio in applied materials is <0.5 percent and as near as possible to 0.1 percent.

Numerous studies are in progress on Cd accumulation by crop plants. When information becomes available on the effect of food Cd and Zn on animal uptake of and injury by Cd during life-term studies, perhaps we can make more valid judgments. Now, we can only conclude that if we control the Cd:Zn ratio so that when Zn is injuring the crop enough that the farmer will lime or change crops to prevent injury from Zn, that the Cd content will not be a hazard by FDA regulatory standards; hence, the <0.5 percent Cd of the Zn content.

TABLE 13
Zn:Cd Ratio In Chard Leaves

Added Zn ppm	*5.3*	*Soil pH 6.4*	*7.2*
		Cd/Zn (%)	
1.31	1.90	0.69	5.31
32.7	1.56	1.68	2.16
65.4	1.24	1.87	2.49
131.	0.96	1.26	2.03
262.	1.00	1.24	2.09

Benefits of Zn and Cu In Sludge and Effluent

The micronutrients Zn and Cu are often deficient or marginally sufficient in agronomic soils. This results in low levels of Zn in crops and thus less Zn is available in the diet of animals. Because many people do not, or will not, supplement their low Zn diet, we must find some way to increase food Zn. Recent reports show that some teenagers' diets are low or deficient in Zn and clinical Zn-deficiency symptoms have been observed[18]. Zn and Cu in sludge or effluent can be considered fertilizers when they correct deficiencies (including that induced by the excess PO_4 added with sludge). Fiskell *et al.*[14] and Parsa[34] found sludge to be an excellent Cu or Zn fertilizer. Most soils could be improved by adding a little sludge with its beneficial N, P, O.M., Zn, and Cu. Thus sludge could lead to higher crop Zn levels (at least in leaf crops) and thereby help to correct the problem of low Zn in the food chain.

Current Recommendations

I feel that there are two bases for recommendations for toxic metals to be added to *agricultural* soils as sludge or effluent. These are: (1) Benefit:risk ratio, and (2) limitation of metal additions to permit continued *general* farming.

The benefits of sludge and effluent include water, O.M., N, PO_4, Zn, and Cu. Risks include the toxic metals which should be minimized wherever possible. Table 14 shows the reasonably attainable (in 1973) minimum toxic metal content. Higher than minimum Cd, Co, Cr, Ni, Pb, Hg, and B contents are a result of industrial pollution. Zn and Cu in digested sludge probably will never drop below 500 and 200 ppm, respectively. The metal content shown in Table 14 represents an attainable, reasonable, toxic metal content for digested sludge, and hence a good benefit:risk ratio for land application. Sludges and higher toxic metal contents should not be applied to *agricultural* land. These criteria (except the Cd:Zn ratio) need not apply to dedicated disposal sites not used to grow crops for sale.

If the composition of a sludge meets the above recommendation, our next consideration is to limit toxic metal additions to levels which permit continued *general* farming on the amended soil even after the added O.M. is gone and an equilibrium of metals and PO_4 has been reached. Because lowering the soil pH below 6.5 leads to extensive increase in toxic metal availability to plants, some assumption has to be made about the pH of the amended soils. Thus, I presume that the toxic-metal-amended (sludge or effluent) soil used for food crops will be maintained at pH 6.5 or above.

TABLE 14
Metal Content of
a Sludge Appropriate
for Land Application

Element	*Content*
Zn	< 2000 ppm
Cu	< 800 ppm
Ni	< 100 ppm
Cd	< 0.5 % of Zn
B	< 100 ppm
Pb	< 1000 ppm
Hg	< 15 ppm

Chumbley[11] recommended that no more than 250 ppm Zn equivalent of toxic metals be added to soils (at pH ≥ 6.5) in any 30-year period. This recommendation did not account for any of the important soil variables except pH. Leeper[25] suggested that we could add toxic metals up to five percent of the C.E.C. (at pH 6.5). The five percent of C.E.C. figure would still allow appreciable injury to metal-sensitive crops at pH 5.5. At pH > 6.5, the Zn and Cu would only serve as fertilizers.

Thus, I believe that toxic metal additions to agricultural soils should not exceed Zn(equivalent) levels equal to five percent of the C.E.C. of the unamended soil (at pH ≥ 6.5). When our knowledge of the reversion process, of O.M. disappearance, of PO_4 effects, and of metal interaction increases, this limit may likely be set higher. With our present knowledge, five percent of C.E.C. appears to be sufficient to protect our agricultural soil resources.

Many of these recommendations relate to application of sludge. Table 15 presents the 1972 Water Quality Criteria for irrigation water and estimation of toxic element accumulation in soils. Based on criteria, metals may accumulate to toxic levels.

TABLE 15
Water Quality Criteria, 1972: Irrigation Water

		Estimated soil balance after 100 years		
	Maximum	*Accumulation*[1]	*Removal*[2]	
Element	*mg/l*	*lb/A*	*ug/g* *lb/A*	*% of* *Added*
B	0.75	600	10	1.7
Cd	0.010	8	0.2	2.5
Co	0.050	40	1.0	2.5
Cu	0.20	160	10	6.2
Pb	5.0	4000	0.05	-
Mo	0.010	8	0.5	6.3
Ni	0.20	160	5.	3.1
Zn	2.00	1600	200	12.5

[1] From 3 acre-ft/ acre/ year.
[2] Corn grain at 167 Bu/ A.

History of Metal Toxicity

There are numerous examples of metal toxicity in agriculture. Toxic amounts of Cu, Zn, or Ni have accumulated in soils from fungicides, unneeded fertilizers, and sewage sludge, or have occurred naturally. Most toxicities have occurred under intensive agricultural practices, such as orchards, vineyards, or vegetable fields, and can be quite expensive to alleviate. Delas[12] and Reuther and Smith[37] have summarized much of this information. These results seldom can be related to disposal of sludge or effluent because of the high O.M. and PO_4 in land application sites.

Metal toxicity from field application of sludge and effluent has been observed in England[35] and other areas. These toxicities to crops generally have occurred in unmanaged situations most favorable for toxicity: low pH, sandy soils, high metal sludges, and/ or metal-sensitive crops. These toxicities have often been alleviated by liming to higher soil pH. However, one of Patterson's examples, a "market garden in Somerset," involved an organic soil with very high metal content. In this case, the only choice was to stop growing sensitive crops. This case also relates to Leeper's example of destruction of O.M. over a period of years.

The available reports are very difficult to interpret because the information is so sparse. To interpret reports on metal toxicity, we need data on soil pH, C.E.C., O.M., total and available Zn, Cu, Ni, Cd, Pb, PO_4, and toxic metal contents of crops grown in comparison with control treatments. The "Woburn Market Garden Experiment" with sewage sludge was lost by plowing for 20 years[27] and no meaningful information was obtained except a warning to look harder at toxic metals. Rohde's[38] report does not include plant analysis and other information needed to interpret his observations.

Until we have more field knowledge of toxic element injury and accumulation from sludges and effluents, we will not be sure we are dealing with all of the potential problems. Lunt[28] and Anderson[1] warned of toxic metals. Experiments in progress in the U.S., England, and Sweden are attacking these questions and should provide the information needed to set firm guidelines to protect soils and the food chain.

Major Questions Remaining

A. The extent of crop species and varietal differences in tolerance to and accumulation of toxic metals. The effect of season (as with Pb) and plant part (leaf vs grain) on toxic metal entry to the food chain.

B. We know far too little about Cd movement from soil to edible plant part to food in the marketplace.

C. We know very little about the nature and permanence of reversion of toxic metals in different soils; effects of Fe, Mn oxides, silicate, O.M., PO , etc.

D. We need more basic knowledge on crop and management effects on soil O.M. as it relates to control of available excess Cu, Ni, and Zn.

E. We know almost nothing about toxic metal interactions (synergistic toxicity) and the importance and mechanism of PO interaction with Zn, Cu, Ni, Cd, Pb, and Hg to alleviate toxicity and prevent plant transport of these toxic elements.

We especially know little about the above in actual field practice. Study of ongoing, older, land application of sludge and effluent sites would significantly complement the current laboratory, greenhouse, lysimeter, and field studies of these practices.

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DISCUSSION

QUESTION: Tom Hinesly, Office of the Undersecretary of the Army. I just wanted to ask Dr. Chaney if he considered how much land would be needed for the disposal of all the sludges that are produced in the United States, and just how big a factor this is from the standpoint of the food chain? According to my calculations and what some of the other speakers have said about reasonable and safe rates, we are only talking about less than ten million acres of land as compared to 465 million acres. I also wondered what you might have to say about the use of this from a standpoint of reclaiming strip mine lands which contain some of these metals in higher concentrations than are found in sludges?

ANSWER: We have looked at your estimates Tom. The ten million acre estimate. And that is presuming the attitude of continual, inperpetuity disposal on those ten million acres. If we took sludges as they are today, instead of the 500 zinc and 200 copper that they can be, we would use those ten million acres up before a century was gone. Which ten million do we take the next century and then century after that?

Strip mines. It is clear from everybody's work now, including some of our own, that the high amount of phosphate we add as sludge is very important at curing the already existing metal toxicity of strip mines. Usually we raise the pH at the same time. They are going to be no better when the organic matter is decayed to the climatic equilibrium and any other soil, and if we add a thousand or ten thousand or what ever ppm zinc, and the copper and nickel and cadmium that go along with it, we are going to have the same problem because somebody is going to do something with that site. Somebody is going to bring the question up about the wildlife on the dedicated land at the Chicago site, that we can't eat anything we shoot on that site. Somebody is going to bring that up and I think we have to accept that responsibility too.

QUESTION: William Bauer, Bauer Engineering, Chicago. In relation to the philosophy of using a site as a relatively permanent place to park heavy metals, have you given any consideration to the reclaiming of those heavy metals through a mining operation. The reason I mentioned that to you the other day, Rufus, I described how we already got almost seven thousand pounds per acre in the upper seven inches of soil in our Arcola Project, and we plan to go to maybe twenty thousand pounds per acre and that stuff might be worth maybe an average of 30 or 40 cents a pound, so, we would have quite a bit of metal there. I know from our lab work that we can reclaim some of this. I was just wondering if you gave any consideration to that?

ANSWER: We have talked about it enough to know that the cost of reclaiming it, there is an awful lot left at the factory, that some factories can actually make money by reclaiming their metal waste and particular things like cadmium and some of the other semi-value metals. If they are claimed at the factory, they usually dump right back into their process so they can be sold as reclaimed, relatively pure metal. By the time it reaches the sewerage plant, it becomes almost inseparable. And then it is only if it is so toxic that it shouldn't be put on land in the first place unless it is dedicated land. Leaper mentioned, "let's put it on land and then shove the top foot away and start again." It is a good idea for dedicated land, not for farm land.

QUESTION: William Bauer, Bauer Engineering, Chicago. I would agree with you for the ongoing work, but we do have a lot of accumulated sludges that we already have on hand, that have a lot of metals in them and there isn't anyway to deal with those.

ANSWER: If the site could become a food chain hazard we can't put it on land. There is a representative from Food and Drug who addressed this question in the workshops in particular, and I think that that really needs to be saved because it is another half an hour discussion.

Crop Selection and Management Alternatives —Perennials—

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INTRODUCTION

The purpose of this paper is to present an overview of our current state of knowledge concerning the use of *perennials* as the vegetative cover on sites to be used for the disposal of treated municipal sewage effluent and/ or sludge. An attempt will be made to briefly review what has been reported in the literature on the subject and to point out gaps in our current state of knowledge and areas of needed research. Hopefully, this review will set the stage and provide a point of departure for discussions in the Workshop on Soil-Nutrient Relationships & Crop Selection and Management.

Selection of the vegetative cover to be utilized or established and maintained on a spray irrigation site depends upon many factors. The following are some of the criteria which should be considered:

1. Water requirements and tolerance
2. Nutrient requirements and tolerance
3. Optimum soil conditions for growth
4. Season of growth and dormancy requirements
5. Sensitivity to toxic heavy metals and salts
6. Nutrient utilization and renovation efficiency
7. Ecosystem stability
8. Length of harvesting rotation
9. Insect and disease problems
10. Natural range
11. Demand or market for the product

The obvious primary choice one has is between a perennial agricultural crop and forest vegetation. The advantages and disadvantages of each will be discussed.

Agronomic Crops

Perennial grasses appear to be the most suitable for wastewater disposal sites and have received the most attention. In general, they have fiberous root systems, are sod forming which aids in erosion control and provides for high infiltration rates, are tolerant of a wide range of ecological conditions, have a long period of growth and have a high uptake of nutrients. Results of investigations with reed canarygrass at the Penn State Project will be cited as an example of using a perennial grass in a land management system.

Crop Yields and Renovation Efficiency

An area of reed canarygrass was irrigated with treated municipal sewage effluent at two inches per week from 1965 to 1969 and with a combination of effluent and liquid digested sludge in 1970. During the six years, yields varied from 4.32 to 7.03 tons per acre. More important, however, is the nutrient content and the amount of nutrients removed in the harvested crops. Under the "living filter" concept of land disposal the higher plants growing on the site are an integral part of the system and assist the microbiological and physio-chemical activities occurring within the soil to renovate the wastewater. The contribution of the vegetative cover to the renovation process adds durability to the system. Average nutrient composition and quantities of nutrients removed by reed canarygrass during 1970 are given in Table 1. It is readily evident that substantial amounts of nutrients can be removed in the harvested crop. These

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amounts are considerably greater than that removed by row crops, particularly in respect to nitrogen. For instance, the harvest of corn silage irrigated at the same level during the same year removed only 160 pounds of nitrogen and 43 pounds of phosphorus.

The amounts of nutrients removed annually by the grass will vary with the amount of wastewater applied, amount of rainfall, length of the growing season, and the number of cuttings.

TABLE 1
Average Nutrient Composition and Quantities of Nutrients Removed by Reed Canarygrass Irrigated with Two Inches of Effluent During 1970[7]

Nutrient	*Average Nutrient Composition*	*Total Amount Removed*
	%	Pounds per acre
Nitrogen	3.69	408.2
Phosphorus	0.50	56.0
Potassium	2.23	246.9
Calcium	0.40	44.2
Magnesium	0.36	40.4
Chloride	1.57	158.4
	ug/g	
Sodium	309	3.4
Boron	8	0.09

The efficiency of the crop as a renovating agent can be assessed by computing a "renovation efficiency" expressed as the ratio of the weight of the nutrient removed in the harvested crop to the weight of the same nutrient applied in the wastewater.

During the six year period, 2127 pounds of nitrogen were applied to the reed canarygrass area in 536 inches of sewage effluent and sludge. A total of 2071 pounds were removed in the harvested crop resulting in a renovation efficiency of 97.3 percent.

During the same period of time, 797 pounds of phosphorus were applied in the wastewater and 279 pounds removed in crop harvest for an overall renovation efficiency of 35 percent. Annual renovation efficiencies varied from 24 to 63 percent. Hence, it is obvious that some other process than utilization of the vegetative cover must be used to assure the removal of this key eutrophic nutrient. This additional renovation and removal of phosphorus is usually accomplished by way of the large withholding capacity of most agricultural soils for phosphorus.

Nutrient Balances

Phosphorus and nitrogen balances were calculated for the reed canarygrass area and are given in Table 2.

After six years 797 pounds of phosphorus and 2127 pounds of nitrogen had been applied to each acre. Harvested crops removed 279 pounds of phosphorus. Since the concentration of phosphorus in the percolate at the four foot soil depth was only 0.05 mg/l and was no greater than that in an unirrigated adjacent forest area, the net percolation losses of phosphorus from the wastewater treated areas were assumed to be proportional only to the excess percolation induced by the added wastewater. Further, since precipitation always exceeds potential evapotranspiration on an annual basis, the wastewater was assumed to be totally recharged. On the basis of these assumptions, the net percolation loss of phosphorus from the wastewater irrigated areas was calculated to be 6.4 pounds per acre during the six year period, or only 0.8 percent of the amount applied. Thus, the soil with its strong absorptive capacity for phosphorus, together with the crop harvests, has persistently removed 99.2 percent of the added phosphorus.

Nitrogen removals by the soil and crop system have also been equally efficient. Over the six year period 2127 pounds of nitrogen were added to each acre. Protein removed in the harvested reed canarygrass was equivalent to 2071 pounds of nitrogen

TABLE 2
Phosphorus and Nitrogen Balances for Reed Canarygrass Irrigated with Effluent at Two Inches Per Week During the Period 1965 to 1970[7]

	Amount Applied		*Removed*		*Retained*
Period	*Wasterwater*	*Nutrient*	*By Crop*	*By Leaching*	*By Soil*
	inches	lbs/acre	lbs/acre	lbs/acre	lbs/acre
1965-70	536	797(P)	279(P)	6.4(P)	512(P)
		2127(N)	2071(N)	452(N)	-396(N)

per acre. Kjeldahl nitrogen content of the upper foot of soil was approximately 5000 pounds per acre. Average concentration of nitrate-N in the percolate at the four foot soil depth during the six-year period was 3.5 mg/l in the effluent irrigated areas and 0.2 mg/l in the control areas. On the basis of the same assumptions used above, the excess percolate from the 536 inches of wastewater applied per acre would have carried a total of 452 pounds of nitrogen into the groundwater. This quantity is 396 pounds in excess of the 56 pounds per acre difference between the amount of nitrogen added in the wastewater and the amount removed in the harvested crops and could easily have been derived from the large amounts of native soil nitrogen. Thus the reed canarygrass was effective in removing 97.3 percent of the added nitrogen.

Wastewater Renovation

The overall effectiveness of the perennial grass management system to accept and renovate wastewater is shown by the decrease in average nutrient concentration in percolating water. The mean annual concentrations of phosphorus at three soil depths are shown in Table 3. After six years, (1965-70), the average concentration of phosphorus was only 0.038 mg/l indicating a 98.9 percent decrease in the average concentration. The efficiency of the perennial grass system is further demonstrated by the fact that the reed canarygrass area received 180 inches more wastewater than an adjacent corn silage area and average phosphorus concentration at the 6-inch depth was only 0.161 mg/l in comparison to 0.138 mg/l on the corn area.

Mean annual concentrations of nitrate-nitrogen at three soil depths are given in Table 4. It is similarly obvious that the reed canarygrass system was equally efficient in maintaining NO^3-N levels below the 10 mg/l limit recommended for drinking water.

In summary, it appears that there is sufficient evidence to indicate that perennial grass management

TABLE 3

Mean Annual Concentration of Phosphorus in Suction Lysimeter Samples at Three Depths and in the Applied Wastewater in the Reed Canarygrass Area Receiving Two Inches of Wastewater Weekly from 1966 to 1970[7]

Lysimeter Depth	*1966*	*1967*	*1968*	*1969*	*1970*
inches			concentration - mg/l		
6	0.164	0.128	0.218	0.186	0.161
24	0.091	0.110	0.120	0.089	0.067
48	0.055	0.053	0.052	0.035	0.038
Wastewater	7.690	7.695	8.450	4.185	3.490

TABLE 4

Mean Annual Concentration of Nitrate-Nitrogen in Suction Lysimeter Samples at Three Depths in the Reed Canarygrass Area Receiving Two Inches of Wastewater Weekly During the Period 1966 to 1970[7]

Lysimeter Depth	*1966*	*1967*	*1968*	*1969*	*1970*
inches			*concentration - mg/l*		
6	0.8	0.6	0.7	0.6	1.2
24	2.2	1.5	1.8	1.1	0.8
48	3.7	3.3	3.1	2.5	2.4

systems are adaptable to municipal wastewater disposal sites, that increased crop yields can be achieved and that the wastewater can be satisfactorily renovated. There, are however, still some unanswered questions relative to the grazing of livestock on disposal sites and the feeding of forage to livestock. There is little documentary evidence on the nutritional adequacy of sewage effluent and sludge produced forage, possible toxicity problems associated with effluent residues on vegetation or accumulation of elements in vegetation, or potential parasitic infections of cattle grazing on wastewater irrigated pastures.

Forests

Forests and brushland often receive high priority as potential areas for wastewater disposal because they usually occupy rural areas and land values are relatively low in comparison to highly productive agronomic areas. The use of forests for wastewater disposal has not been extensively studied. Several projects are currently underway but little information has yet been published to provide the necessary data for decision making and design purposes relative to land disposal projects under the varying soils and climatic conditions in the various forest regions of the United States.

Treated municipal sewage effluent has been spray irrigated in forested areas for a ten year (1963-1972) period at the Penn State Project. The results of this research will be used to illustrate the relative merits of a forest management system. Forested areas irrigated consisted of a mixed hardwood forest, a red pine plantation *(Pinus resinosa)*, and a sparse white spruce *(Picea glauca)* plantation established on an abandoned old field. Detailed descriptions of these areas have been previously reported by Sopper[5,6].

Sewage effluent was applied in various amounts ranging from 1 inch per week to six inches per week and over various lengths of time ranging from 23 weeks during the growing season to the entire 52 weeks. Rate of application was 0.25 inch per hour.

Wastewater Renovation

Nitrogen and phosphorus are the two key eutrophic elements in municipal sewage effluent and therefore discussions on renovation will be limited to these two elements.

The forested areas were highly efficient in removing phosphorus. During the past ten years, the average concentration of phosphorus in the effluent sprayed on the land, ranging from 0.5 to 10 milligrams per liter (mg/ l). The forest biosystem was able to decrease the phosphorus concentration by more than 90 percent at the two-foot soil depth under all application rates. During the tenth year (1972), the average concentration of phosphorus in the effluent was 4.505 mg/ l. This concentration was diminished to values ranging from 0.037 to 0.200 mg/ l at the four-foot soil depth indicating renovation percentages from 95 to 99 percent in the various forested areas. In control areas the percolating water at the same soil depth had phosphorus concentrations ranging from 0.035 to 0.113 mg/ l. These values are not very different from the effluent-irrigated plots considering that up to 50 feet of sewage effluent had been applied over the ten-year period.

The efficiency of the forest areas to reduce nitrogen concentrations has been variable. Average annual concentrations of nitrate-nitrogen in soil water percolate samples collected at the 48-inch depth are given in Table 5.

It is clear that the forested areas can handle a one-inch per week application without having the mean annual concentration of nitrate-nitrogen at the 48-inch depth exceed the Public Health Service limit. However, when two inches were applied per week either in the April-November period with red pine on the Hublersburg clay loam soil or year-around with hardwoods on the Morrison sandy loam soil the NO_3-N concentration at the 48-inch depth rapidly exceeded the Public Health Service limit. On the other hand, two inches of wastewater applied weekly on the old field area on the Hublersburg clay loam soil in the April-November period did not result in excessive NO_3-N values at the 48-inch depth.

The difference between the two-inch red pine and two-inch old field areas on the same soil type probably resides in the difference in the recycling of the nitrogen through the two vegetative covers. In the red pine, relatively less nitrogen is assimilated in the annual growth than in the herbaceous annuals and perennials in the old field and larger amounts of readily decomposable organic residues are deposited annually in the old field. The larger quantities of carbonaceous material in the old field area may also promote a higher degree of denitrification in this fine textured soil. The sandiness of the Morrison soil on the two-inch hardwood area would not be conducive to denitrification of the larger nitrogen load applied in a year-around irrigation period and the hardwood leaf litter although more decomposable than the red pine needle litter would not be as decomposable as the old field residues.

The explanation above was corroborated when the two-inch red pine area was clearcut after many of the trees were felled by a heavy wet snow and windstorm in November, 1968. After the clearcutting the area grew up to a dense cover of herbaceous vegetation similar to that on the irrigated old field area. A large mass of carbonaceous was deposited on the surface in the fall of 1969 and in 1970 another dense cover of herbaceous vegetation was produced and the mean

TABLE 5
Mean Annual Concentration (mg/ 1) of Nitrate-Nitrogen in Suction Lysimeter Samples Collected at the 48-Inch Soil Depth in Forest Areas Receiving Various Levels of Wastewater During the Period 1965-1970[7]

	Red Pine Hublersburg Soil inches per week			Hardwood Hublersburg Soil inches per week		Old Field Hublersburg Soil inches per week		Hardwood Morrison Soil inches per week		Hardwood Hublersburg Soil inches per week	
Year	*0*	*1*	*2*	*0*	*1*	*0*	*2*	*0*	*2*	*0*	*4*
1965	0.9	2.2	3.9	--	0.0	0.3	8.0	--	--	--	2.3
1966	0.1	2.1	9.3	0.1	0.2	0.1	5.0	0.1	10.6	0.1	9.1
1967	0.9	1.7	13.8	0.3	1.4	0.3	6.1	1.4	19.2	0.3	3.4
1968	0.9	2.7	19.9	0.1	8.0	0.2	3.7	0.1	25.9	0.1	0.9
1969	0.2	4.2	24.2	0.1	7.2	0.2	2.3	0.3	23.7	--	--
1970	< 1	5.3	8.3	< 1	5.0	< 1	3.5	1.0	42.8	--	--
Ave.	0.6	3.0	13.2	0.2	3.6	0.2	4.8	0.6	24.4	0.2	3.9

annual concentration of NO_3-N dropped from a value of 24.2 mg NO_3-N/ l in 1969 to a value of 8.3 mg NO_3-N/ l in 1970 and to 3.8 mg NO_3-N/ l in 1971.

Further support for the importance of denitrification in decreasing the inputs of nitrate to the groundwater was obtained in the data from the hardwood forest on the Hublersburg soil which received four inches of wastewater, weekly in the April-November period (Table 5). In spite of doubling the nitrogen load, the NO_3-N concentration at 48 inches remained below 10 mg/ l, probable because the larger hydraulic load encouraged more denitrification.

Tree Growth Responses

Red Pine. Experimental plots were established in a red pine plantation in 1963. These plots have been irrigated with sewage effluent during the past ten years at rates of one inch and two inches per week during the growing season (April to November). The plantation was established in 1939 with the trees planted at a spacing of eight by eight feet. In 1963 the average tree diameter at breast height was 6.8 inches and average height was 35 feet.

Diameter and height growth measurements were made annually. Average annual growth for the period 1963 to 1970 is given in Table 6. Irrigation with sewage effluent at both rates produced slight increases in height growth during the first two years. This slight increase in height growth has been maintained on the plot receiving one inch per week. However, on the plot receiving two inches per week, height growth continually decreased up to 1968 when high winds following a wet snowfall completely felled every tree on the plot.

Diameter growth was measured annually with dendrometer bands. In addition increment cores were taken in 1972 from sample trees in all areas. The actual measurements of average radius growth taken from the increment cores indicate that the previous diameter growth data reported which was based upon dendrometer band measurements of tree circumferences was incorrect[6]. Average annual diameter growth based on increment core measurements is given in Table 7. Irrigation at the one-inch-per-week level increased the average annual diameter growth by 183 percent. On the other hand, the two-inch-per-week level actually caused a reduction in diameter growth. In addition, during the sixth year of irrigation the needles of the pines being irrigated at the higher rate began to turn yellow. This result was not

TABLE 6
Average Annual Terminal Height Growth of Red Pine Irrigated with Sewage Effluent

Treatment	*Average Annual Height Growth*
	feet
Irrigated - 1 inch per week	1.8
Control	1.4
Irrigated - 2 inches per week	1.6
Control	1.7

TABLE 7
Average Annual Diameter Growth of Red Pine Irrigated with Sewage Effluent

Treatment	*Average Annual Diameter Growth*
	inches
Irrigated - 1 inch per week	0.17
Control	0.06
Irrigated - 2 inches per week*	0.06
Control	0.07

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* For period 1963 to 1968 only.

totally unexpected since other investigators have reported red pine growth to be adversely affected on wet soils and to be sensitive to boron toxicity. Approximately four pounds of boron per acre are applied annually in the sewage effluent. Other investigators have previously reported that applications of 1.1 pounds of boron per acre were sufficient to induce city symptoms.

White Spruce. Two experimental plots were established in a sparse white spruce plantation on an abandoned old-field area. The trees in 1963 ranged from three to eight feet in height. One plot has been irrigated with sewage effluent during the past ten years at the rate of two inches per week, while the second plot has been maintained as a control. Height growth measurements have been made annually. In 1972, all tree diameters were measured and increment cores taken to determine the average annual diameter growth.

Total height of the trees were measured in August 1972. Average height of the trees on the irrigated plot was 20 feet and ranged from 12 to 25 feet. The average height of the trees on the control plot was nine feet and ranged from 8 to 15 feet. Over the ten-year period average annual height growth was 18 inches on the irrigated areas and five inches on the control areas, representing a 360 percent increase as a result of sewage effluent irrigation.

Average diameter of trees on the irrigated plot was 3.7 inches in comparison to 1.1 inches on the control plot. Measurements taken from increment cores indicated that the average annual diameter growth on the irrigated trees was 0.40 inch and on the control trees 0.18 inch, representing a 122 percent increase.

Mixed Hardwoods. A hardwood forest, consisting primarily of oak species, was irrigated with sewage effluent at rates ranging from one inch to four inches per week and for periods ranging from the growing season (23 weeks) to the entire year (52 weeks). Principal species were white oak *(Quercus alba)*, chestnut oak *(Q. prinus)*, black oak *(Q. velutina)*, red oak *(Q. rubra)*, scarlet oak *(Q. coccinea)*, red maple *(Acer rubrum)*, and hickory *(Carya spp.)*.

Average annual diameter growth during the 1963 to 1972 period is given in Table 8. One inch per week applications produced only slight increases in diameter growth; however, the two- and four-inch-per-week levels results in 69 and 40 percent increases, respectively. These values pertain primarily to the oak species. Some of the other hardwood species present on the plots have responded to a greater extent. For instance, increment core measurements made on red maple *(A. rubrum)* and sugar maple *(A. saccharum)*, indicate that the average annual diameter growth during the past ten years has been 0.43 inch on the trees irrigated with one inch of effluent per week in comparison to 0.10 inch on control trees, a 330 percent increase in average annual diameter growth. Similarly, increment core measurements made on aspen *(Populus tremulodies)* irrigated with two inches of effluent weekly during the growing season indicated that the irrigated trees had an average annual diameter growth of 0.47 inch in comparison to 0.24 inch for unirrigated trees, a 96 percent increase in growth. Saplings which averaged 0.65 inch in diameter in 1963 increased in diameter to an average of 5.3 inches on the irrigated areas by 1972 in comparison to 3.1 inches on the control areas.

TABLE 8
Average Annual Diameter Growth in Hardwood Forests Irrigated with Sewage Effluent

Weekly Irrigation Amount	*Average Diameter Growth*	
	Control	*Irrigated*
inches	inch	inch
1*	0.16	0.18
2* *	0.13	0.22
4* * *	0.15	0.21

* Irrigated with one inch of sewage effluent weekly during growing season from 1963 to 1972.

* * Irrigated with two inches of sewage effluent weekly during the entire year from 1965 to 1972.

* * * Irrigated with four inches of sewage effluent weekly during the growing season only from 1963 to 1967; during the dormant season only from 1968 to 1971; and with two inches of effluent weekly during the growing season in 1972.

Renovation Efficiency

The nutrient element content of the foliage of the vegetation on the irrigated plots was consistently higher than that of the vegetation on the control plots. It is therefore obvious that the forest vegetation is contributing to the renovation of the percolating effluent; however, its order of magnitude is difficult to estimate because the annual storage of nutrients in the woody tissue and the extent of recycling of nutrients in the forest litter are extremely difficult to measure. Although considerable amounts of nutrients may be taken up by trees during the growing season, many of these nutrients are redeposited annually in leaf and needle litter rather than being hauled away as in the case of harvested agronomic crops.

A comparison between the annual uptake of nutrients by an agronomic crop (silage corn) and a hardwood forest is given in Table 9. It is obvious that trees are not as efficient renovating agents as agronomic crops. Whereas harvesting a corn silage crop removed 145 percent of the nitrogen applied in the

TABLE 9
Annual Uptake of Nutrients by a Silage Corn Crop and a Hardwood Forest Irrigated with Two Inches of Effluent Weekly During 1970

Nutrient	*Corn Silage Pa. 602-A*	*Renovation Efficiency**	*Hardwood Forest*	*Renovation Efficiency*
	lbs/acre	%	lbs/acre	%
N	161	145	84	39
P	42	143	8	19
K	129	130	26	22
Ca	27	15	22	9
Mg	23	27	5	4

---

* Percentage of the element applied in the sewage effluent that is utilized removed by the vegetation.

sewage effluent, the trees only remove 39 percent most of which is returned to the soil by leaf fall. Similarly only 19 percent of the phosphorus applied in the sewage effluent is taken up by trees in comparison to 143 percent of the corn silage crop.

Wood Fiber Quality

A review of the literature indicates that numerous studies have been made concerning forest fertilization and forest irrigation but only a few studies have been made concerning the combined effects of fertilization and irrigation on forest tree growth. Moreover, almost no data is available on the effects of municipal wastewater irrigation on the anatomical and physical properties of the wood of forest trees. The results of a recent study by Murphey *et. al.*[4], provides some insight along these lines for the species red pine and red oak.

They reported that sewage effluent irrigation on red pine resulted generally in increased specific gravity, increased tracheid diameter, decreased cell wall thickness, and no change in tracheid length.

Positive changes also occurred in the red oak wood due to irrigation with sewage effluent. They reported a five percent reduction in the earlywood vessel segment diameter. These large barrel-shaped elements are the causes of "picking"—the lifting of the surface of paper during printing. The smaller, longer cells produced by effluent irrigation might reduce this problem when using ring porous woods such as red oak for pulp. An increase in the number and height of broad rays resulted in an increase in the amount of wood volume occupied by the broad rays from nine percent in the untreated xylem to 11.5 percent of the wood laid down during irrigation. The increase in number and height of broad rays would cause an increase in the percentage of "fines" in a pulp mix. Increase in specific gravity and particularly in the change in the amount of latewood from about one-half to three-quarters of the growth ring provides more mass of fibers per unit volume. Coupled with the growth rate change, irrigation with municipal wastewater results in the development of more fiber per treated tree. The increase in fiber and vessel segment length also increased the utility of this wood for pulp. Wangaard and Williams[9] have shown a relationship exists between fiber and length and tear strength for known paper sheet densities and fiber strength. The longer the fiber the stronger the paper for a given fiber strength below a critical sheet density.

Murphey *et. al.*[4], concluded that in general the alterations of the wood fibers resulting from wastewater irrigation enhanced their utilization as a raw material for pulp and paper.

Ecosystem Stability

Ecosystems are somewhat elastic and can withstand a certain amount of stress prior to permanent change or collapse. Weekly application of wastewater will certainly impose a stress on the ecosystem. An unresolved question is whether the impact will be sufficient to cause a significant change and whether the change will be desirable or undesirable. Regular applications of large volumes of wastewater can turn a relatively dry site into a moist super-humid site and a relatively sterile site into a fertile one. Such changes may influence species composition and plant density on the site as well as fungi, bacteria, and microorganism types and populations. These changes, in turn, may influence the habitat and utilization of the site by wildlife. In general these changes are subtle and occur over a long period of time. Since there are no municipal wastewater spray irrigation projects in the United States older than ten years on which the ecosystems have been monitored annually, we can only conjecture the long term effects. Some of the results from the Penn State Project will illustrate some of the trends observed during the past decade.

Forest Reproduction

A mature mixed hardwood forest was irrigated with sewage effluent at the rate of one inch per week during the growing season from 1963 to 1972. Measurements made on milacre plots in 1972 indicated a drastic reduction in the number of tree seedlings present in the irrigated area. The initial survey in 1964 indicated about 15,800 tree seedlings per acre in the control area with a slight reduction to 13,600 in 1972. However, in 1964 (the second year of irrigation) there were 14,500 tree seedlings per acre present in the irrigated area and only 1,830 in 1972. No conclusive evidence is yet available to explain these results. Soil sample analyses and climatic data are currently being evaluated for a possible explanation. These results may be partially due to the fact that effluent irrigation stimulates leaf growth which produces a more dense canopy and reduces light intensity at the forest floor. Average light intensity under the canopy in the irrigated area was less than 50 percent of that under the control plot canopy.

A similar reduction was also found in the number of herbaceous plants in the irrigated forest area. The initial survey in 1964 indicated about 86,333 stems per acre, whereas in 1972 there were only 14,800 stems per acre. On the control area, the 1964 survey indicated 63,170 stems per acre in comparison to 25,000 stems per acre in 1972.

Old Field Herbaceous Vegetation

An old field area consisting primarily of proverty grass *(Danthonia spicata)*, goldenrod *(Solidago spp.)* and dewberry *(Rubus flagellaris)* was irrigated with sewage effluent at the rate of two inches per week during the growing season from 1963 to 1972. Significant changes have been observed in species composition, vegetation density, height growth, dry matter production, percentage areal cover, and nutrient utilization.

Average dry matter production during the ten-year period was 5457 pounds per acre on the irrigated plot and 1810 pounds per acre on the control plot. This represents an average annual increase of 201 percent. Annual increases ranged from 100 to 350 percent.

Several species which were predominant prior to wastewater irrigation have been drastically reduced in number or have disappeared completely. For instance, goldenrod *(Solidago spp.)* which had 155,090 stems per acre in 1963 was reduced to 13,612 stems per acre by 1972. White Aster *(Aster pilosus)* which had 122,970 stems per acre in 1963 was not present on the site in 1972. The predominant species on the irrigated plot was clearweed *(Pilea pumila L.)* which covered more than 80 percent of the plot with approximately 19 million stems per acre. This species is typical of shaded moist sites.

Species composition changes are illustrated in Table 10 based on measurements made in 1972. The control plot is representative of pre-irrigation vegetation conditions.

The average height of the predominant plant species on the irrigated plot was five feet in comparison to one foot on the control plot. While the irrigated plot had a complete dense vegetative cover approximately ten percent of the control was barren of vegetation.

TABLE 10
Predominate Herbaceous Vegetation Species on the Irrigated and Control Plots of the Old Field Area in 1972[7]

	Irrigated Plot		*Control Plot*	
Species	*Percent Cover*	*Average Height*	*Percent Cover*	*Average Height*
	%	feet	%	feet
Goldenrod *(Solidago juncea)*	1	2.8	5	1.8
Aster *(Aster spp.)*	0	--	5	1.1
Dewberry *(Rubus flagellaris)*	0	--	40	0.8
Strawberry *(Fragaria vesca)*	5	0.9	10	0.5
Poverty grass *(Danthonia spicata)*	0	--	20	0.3
Everlasting *(Antennaria spicata)*	0	--	5	0.1
Goldenrod *(S. rugosa, S. graminifolia, S. juncea)*	5	5.3	0	--
Milkweed *(Asclepias rubra)*	5	5.1	0	--
Indian Hemp *(Apocynum cannabinum)*	5	3.3	0	--
Night shade *(Solanum dulcamara)*	10	2.3	0	--
Clearweed *(Pilea pumila)*	75	1.5	0	--

Wildlife Habitat

As mentioned previously spray irrigation of municipal wastewater over large areas of forest, brushland, or perennial weeds will certainly affect the value of the site in terms of wildlife habitat. Here again there is a dearth of information. Wildlife studies were only initiated on the Penn State Project in 1971 and, hence, the results obtained to date are largely inconclusive. Wood *et. al.*[10], reported recently that spray irrigation of sewage effluent at the rate of two inches per week in forests and on brushland appeared to have a favorable influence in the nutritive value of rabbit and deer forage. Foliar analysis indicated that crude protein, P, K, and Mg contents here all increased, whereas Ca content was decreased. Reed canarygrass, tested for changes in digestibility due to treatment, showed no significant response with respect to digestible dry matter and protein.

Studies using the lead deer technique to determine preference for or avoidance of irrigated areas indicated that the deer used treated sites as readily as untreated sites. During the winter period observations indicated that wild deer used the irrigated areas for resting and feeding even though these areas were often ice covered as a result of winter irrigation.

No conclusive evidence was obtained on the effects of spray irrigation on rabbit reproduction. However, they did find that the winter carrying capacity of the irrigated sites exceeded that of the control areas presumably due to the higher levels of available nutrition and improved cover conditions. Rabbits trapped on the irrigated areas appeared to be larger and healthier than those on the control area which were as much as a third lighter in weight and showed obvious signs of emaciation.

Since public hunting areas and public gamelands are possible disposal areas, some concern has been expressed by sportsmen on the possible effects on game bird reproduction. It is well known that wet spring season periods have an adverse effect on survival of young broods of wild turkey and grouse. Many of the young chicks die of pneumonia during these cool, wet periods. An unanswered question is whether weekly spray irrigation of wastewater will produce the same condition. Worthy of note is the fact that workers on the project have observed both grouse and mallard ducks nesting in the irrigated plots even though these 0.5 to 1.0 acre plots are surrounded by large areas of unirrigated land.

Special Uses

Under the subject of perennials one might consider a variety of special uses for the spray irrigation disposal site. Most of these are high income products and offer an opportunity for an economic return.

Such uses might include:

1. Christmas tree production
2. Tree seedling nurseries
3. Ornamentals
4. Orchards
5. Silage hybrid poplar, sycamore or cottonwood
6. Sod production
7. Recreation areas and golf courses

Very little research has been done to determine the feasibility of using treated municipal wastewater for these purposes. One can find a few references in the literature on the utilization of sewage effluent for the irrigation of orchards, parks, and golf courses but for the most part there are descriptions of small operating systems at a specific location and not reports of a pre-planned research project designed to provide a complete evaluation of the system.

Reforestation and Reclamation

In contrast to the utilization of an established perennial vegetative cover for spray irrigation, there is also the option of using municipal wastewater for reforestation and reclamation of drastically disturbed areas such as those resulting from strip mining operations. Several research projects have demonstrated the feasibility of this method [2,3,8]. Both tree seedlings and a variety of grasses and legumes have been successfully established on barren spoil banks utilizing various amounts and combinations of sewage effluent and sludge.

Digested sludge, in particular, exhibits its greatest potential when used as a soil amendment. The organic matter content of soils can be increased very rapidly with sludge applications. When applied on heavy textured soils having low organic matter contents, the water infiltration and aeration capacities of the soils may be much improved in a short period of time. Because of its pH buffering capacity, digested sludge is especially valuable when incorporated as a soil amendment in order to change soil pH. Since digested sludge has a near neutral pH, heavy application tends to neutralize both extremely acid and extremely alkaline soil conditions.

There is still a need for more information. For instance, is liquid or solid sludge application more effective? Should the sludge be incorporated into the surface soil? What length of treatment is necessary? Once vegetation is established will it maintain itself if treatments are stopped? How long will disturbed spoil material adequately renovate percolating wastewater? Will heavy metal concentrations in sludge cause problems? There is also a dearth of information concerning the economics of such treatments.

There are more than three million acres of disturbed land in the United States which might be restored to a more aesthetic and productive state through applications of municipal sewage effluent and sludge.

Operation—Annual or Seasonal

The use of perennials in the land management system of the disposal site may depend upon whether spray irrigation will be continued throughout the year or only operated during the warm summer growing season. If annual spray irrigation is contemplated, forests or perennial grasses may have to be used, particularly in the northern climates where temperatures drop and remain below freezing for prolonged periods of time. These vegetation types will normally provide better winter infiltration conditions because of the accumulation of organic matter which provides an insulation layer on the soil surface and reduces soil freezing. In addition, the acid conditions generally associated with forest soils provide a larger phosphorus adsorptive capacity.

Management Problems

Utilization of perennial vegetation on the spray irrigation site generally necessitates the use of a solid-set irrigation system. Some of the potential problems to be encountered can be eliminated through proper design of the irrigation system.

For instance, if a perennial grass is to be used and harvested for silage, the distance between lateral lines should be sufficient to provide access and turning of harvesting equipment. Alternate disposal areas must be available to accept wastewater during the period allowed for field conditions to dry prior to harvest.

Three potential problem areas may be encountered in forested areas. These are (1) ice damage, (2) windthrow, and (3) tree injury by sprinkler spray.

With winter irrigation a certain amount of ice damage must be expected. A survey in a mixed hardwood forest on the Penn State Project following winter irrigation indicated that approximately 52 stems per acre showed visible ice damage in the irrigated area compared to 7.5 stems per acre in the control area. Seventy-five percent of these trees were in the two-inch diameter class. The species most susceptible to ice damage was red maple. It is quite possible that extensive ice damage could effect stand reproduction and alter species composition. Ice damage can be somewhat minimized through the proper design of the spray irrigation system and the use of non-rotating sprinkler or low-trajectory rotating sprinklers.

A survey was also made in 1972 in the same forest stand to determine if ten years of sewage effluent irrigation had any effect on tree mortality. Mortality being defined as standing dead trees above 1.0 inch in diameter. There appeared to be no difference in the amount of mortality in the irrigated and control areas (104 versus 106 trees per acre, respectively).

In dense forest stands or coniferous plantations bark damage and tree injury can be extensive if sprinkler nozzle pressures are too high. Wide lateral line spacings which require high sprinkler nozzle pressures for proper effluent distribution are not applicable if the forest condition is to be perpetrated. Lateral line spacings should be selected so as to permit the use of sprinkler nozzles pressures of approximately 50 psi. This, of course, will result in an increased capital cost for the irrigation system.

Windthrow of trees may also be a problem. Effluent irrigation at rates of one or two inches per week may keep the soil moisture status near field capacity and hence may encourage the development of shallow tree root systems. For instance, at the Penn State Project in November 1968, following a weekly application of two inches of effluent, a heavy snowfall accompanied by strong winds resulted in the complete blow-down of a one-acre red pine plantation. Since then several trees have also been windthrown in the mixed hardwood forests. Most of these trees were adjacent to natural forest openings, agricultural fields or power line rights-of-way. It appears that this problem could be minimized if an unirrigated buffer zone 50 to 100 feet wide were left on the windward side of any irrigated forest area where exposed to an open area. This buffer zone would provide a wind break against prevailing winds.

SUMMARY

It appears that there is sufficient evidence to indicate that perennial vegetation can be utilized as part of the land management system of a municipal wastewater disposal site. There is still, however, a need for much definitive research data on almost all aspects concerning the long-term environmental impacts on the entire biosystem.

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DISCUSSION

QUESTION: Ray Harris, USDA, Forest Service. I was kind of intrigued by the amount of damage you had from irrigating with the sprinklers in winter time. I know that you tried several other practical methods which you dropped, but according to some of the literature you wrote, I was just wondering with the present uproar of clear cutting if you haven't rethought about using another irrigation method beside sprinkling for winter?

ANSWER: We started our winter irrigation with non-rotating type sprinklers in which a single shot of waste-water came out, hit an inverted cone and then distributed like an umbrella. You can eliminate a lot of this winter breakage and damage with these. The only thing wrong with them is that you don't get a very good distribution of effluent in the winter time because it is all diverted out and it all comes off-like on the end of an umbrella, so it is concentrated in a little peripheral circle. So, in terms of renovation, it is poor. So, we eventually, over a course of years, went to rotating sprinklers of a type which did not freeze up. They operate at low trajectory and we just live with the amount of damage because we are, of course, leaning towards the renovation aspects more than the loss of the saplings at this point. You can't go to furrow, you can't go to flooding in forest. I think sprinkler irrigation solid set system in a forest is about the only thing you could consider.

Recycling Urban Effluents On Land Using Annual Crops

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ABSTRACT

Modern cities are faced with the problem of sewage and waste disposal. Treated municipal wastewater has been used for industrial purposes, for recreation, to produce forest products and to grow agricultural crop plants.

Since municipal wastewater contains more fertilizer elements (nitrogen, phosphorus, and potassium) than do most other forms of irrigation water, it offers a future agricultural potential that should be exploited. High yields of relatively high quality food, feed, forage, oil, and fiber plant products have been obtained from crop plants utilizing municipal wastewater as a source of irrigation water and plant nutrients.

Soil irrigated with wastewater had a lower infiltration rate, higher modulus of rupture, and more soluble salts, nitrates, and phosphates than did soil irrigated with well water and fertilized with suggested amounts of nitrogen, phosphorus, and potassium. Irrigation with wastewater (sewage effluent) for 14 years did not decrease field crop yields or result in any adverse effects on soil that could not be corrected with minor changes in field crop culture.

INTRODUCTION

Wastewater (sewage effluent) from municipal and industrial treatment plants is a potential source of irrigation water and plant nutrients for agricultural uses. Relatively few instances of agricultural uses of wastewater in crop production have been recorded. Most of the literature on this subject has been prepared by scientists in the sewage disposal field. Agricultural uses of wastewater aid crop production, make beneficial use of water that would have been wasted, decrease the pollutant load on receiving streams and groundwater, and preserve normal stream flow for downstream uses[14].

Literature Review

Research at Locations Other Than Arizona

Wastewater arising from domestic and industrial use is unfit for further use without some treatment. Even though the increase in solids content because of use is small, it is the nature of the added material rather than the amount that makes treatment necessary. Advances in technology and in health sciences have resulted in sewage treatment plants that produce effluents that are both safe and suitable for irrigation of certain crops. The type of treatment by a sewage plant determines the degree to which suspended solids are removed from sewage. Primary treatment by sedimentation may remove from 25 to 40 percent of suspended solids. Additional treatment by trickling filtration and secondary sedimentation or by the activated sludge process may remove as much as 95 percent of the suspended solids. Chlorination of clarified effluent from modern sewage treatment plants produces reclaimed water that is safe for many reuse applications. It is suited to agricultural applications due to the soluble nitrogen and phosphates that remain

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after treatment. The quantities of these nutrient materials vary widely and should be determined for any effluent considered for reuse. The application of wastewater to agricultural land may serve two purposes: (a) to promote plant growth and crop yields, and (b) to further treat applied wastewater. Wastewater must be adequately treated prior to use on agricultural areas to avoid odor and other nuisance problems. Proper sanitary management dictates that the constant flow of wastewater must be utilized at all times. During periods of heavy rainfall and/ or when crops are not being grown, it may be necessary to provide adequate storage in lagoons or lakes to hold the wastewater in reserve for periods when it can be properly utilized by crops. Modern methods of irrigation management must be employed for the most efficient use of the available supply. The water intake rate and storage capacity of the soil profile must be considered, along with the type of crop to be grown, in determining the area required for the amount of wastewater to be applied. Irrigation must be intermittent and over-irrigation must be avoided if maximum efficiency is to be achieved. Irrigation with wastewater is normally practiced in areas where rainfall is not sufficient during the growing season for maximum crop production[14].

Muller[16] pointed out that settled and biologically treated sewage was used to irrigate pasture crops and fruit trees in Australia. Wierzbicki[19] reported that groundwater supplies in Germany have been increased by the utilization of sewage effluent for surface irrigation. Hershkovitz and Feinmesser[13] noted that sewage effluent from secondary treatment facilities in Israel was suitable for planned irrigation reuse. Scarcity of water in southern Africa made the use of sewage effluent for irrigation attractive and worthy of consideration. Use of wastewater for agricultural and horticultural purposes was good water and fertilizer economy[2].

Mitchell[15] reported that a sewage irrigation farm had been in use since 1928 at Vineland, New Jersey. The farm provided municipal sewage disposal facilities for a population of 8,000 and irrigation with sewage effluent increased crop production on poor soils. Travis[17] pointed out that Southern California's Talbert Water District used effluent from the Orange County Sanitary District's primary sedimentation plant to irrigate 2,800 acres of crop land. Chapman[1] noted that crop yields in Wisconsin were increased by irrigation with water carrying effluent from city sewage disposal systems. Wells[18] reported that farmers near San Antonio, Texas avoid drought by using sewage plant effluent for the irrigation of about 4,000 acres of farm and pasture land.

Research Conducted in Arizona

Dye[12] found that effluent from complete treatment at the Activated Sludge Treatment Plant in Tucson, Arizona contained considerable quantities of the three principal fertilizer elements: nitrogen, phosphorus, and potassium.

The Arizona Agricultural Experiment Station, University of Arizona, Tucson, has been conducting preliminary research on the possible utilization of treated municipal wastewater as a source of irrigation water and plant nutrients in the production of crop plants since 1957. Our research has involved the use of wastewater (liquid effluent) from the Activated Sludge Sewage Treatment Plant in Tucson, Arizona. The treated municipal wastewater looked like ordinary well water but it contained about 65 pounds of nitrogen, 50 pounds of phosphate (P_2O_5), and 32 pounds of potash (K_2O) per acre-foot. It required three acre-feet per acre of wastewater to grow a small grain crop (barley, oats, and wheat) to maturity. Local well water contained ten pounds of N, 0.5 pound of P_2O_5, and 14 pounds of K_2O per acre-foot[6]. Four irrigation and fertilizer treatments were used in our studies: (1) well water with no additional fertilizer (check); (2) well water with suggested fertilizer (100 pounds of N, 75 pounds of P_2O_5, and 0 pounds of K_2O per acre); (3) well water with N, P_2O_5, and K_2O equal to wastewater (200 pounds of N, 150 pounds of P_2O_5, and 100 pounds of K_2O per acre); and (4) wastewater with no additional water or fertilizer.

Experiments were conducted at Cortaro, Arizona to compare the winter pasture forage production from oats irrigated with municipal wastewater with yields obtained when oats were irrigated with well water and fertilized with different amounts of commercial fertilizer. Plantings were made in December and pasture forage was harvested at the jointing stage of growth in March of the following year. The green forage contained from 80 to 85 percent moisture. Oats produced 150 percent more pasture forage when grown on plots that received wastewater than when grown with suggested amounts of well water and commercial fertilizer[6]. When oats pasture forage was grown with wastewater, it contained approximately the same amounts of protein and D.L.N. (Digestible Laboratory Nutrients) as when it was irrigated with well water and fertilized with nitrogen, phosphorus, and potash from commercial fertilizers in amounts equivalent to those supplied in wastewater[10].

A local rancher used wastewater as the only source of irrigation water and fertilizer to grow small grains pasture forage for beef cattle. The pasture had a carrying capacity of four 500-pound steers per acre. During the fall and early winter, the steers made an average gain in weight of about one pound per steer per day. In the late winter and early spring, the steers made an average gain in weight of about two pounds per steer per day. Beef gains of this magnitude compare very favorably with gains obtained from small grains winter pasture grown with regular irrigation water and commercial fertilizer. The foregoing beef gains were considerably higher than gains obtained on the open range during the winter months. The animals drank wastewater instead of well water without any detrimental effects[6].

Very few instances of nitrate poisoning from small grains forage have been verified in Arizona. However, excess nitrate accumulation may occur in plants grown with high nitrogen fertilization under conditions of limited moisture and low light intensity. The danger of nitrate poisoning from small grains forage grown with wastewater was no greater than the danger of nitrate poisoning from small grains grown with well water and commercial fertilizer[8].

Small grains (barley, oats, and wheat) provide excellent hay for beef and dairy cattle. They can be grown during the summer in the cooler regions of the United States and during the winter months in the mild areas of the Southwest. Hay production from barley irrigated with wastewater was compared with hay grown with well water and different amounts of commercial fertilizer. Barley produced as much air-dry hay when it was grown with wastewater as it produced when it was irrigated with well water and fertilized with suggested commercial fertilizer. When grown for hay production, barley appeared to be more sensitive to the constituents in wastewater than did oats or wheat[7]. Concentrations of protein and D.L.N. in hay are measures of its livestock feed quality. When barley was grown with wastewater, it contained more protein and D.L.N. than it contained when it was irrigated with well water and fertilized with nitrogen, phosphate, and potash from commercial fertilizers in amounts equivalent to those supplied in wastewater[11].

High quality grain from barley and wheat is essential for profitable livestock feeding operations in the Southwest. Studies were conducted in Arizona to determine if municipal wastewater could be used successfully as supplemental irrigation water to produce high quality grain from barley and wheat. More grain was produced on barley and wheat plots irrigated with wastewater than was obtained on plots that received well water and N, P, and K in amounts equivalent to those applied during the growing season in wastewater. Barley and wheat utilized the nitrogen in wastewater as efficiently as they used the nitrogen in commercial fertilizer to produce high protein grain. Wastewater had no undesirable effect on the D.L.N. content of grain from barley and wheat[9].

Although it is possible to grow high yields of high quality wheat grain for livestock feed with municipal wastewater, the milling and baking qualities of wheat grain produced with wastewater are lower than the milling and baking qualities of grain irrigated with well water and fertilized with commercial inorganic fertilizers[3].

Studies were conducted in Arizona to determine effects of continued use of municipal wastewater, as a source of irrigation water and plant nutrients, on selected soil properties. The soil was a Grabe silt loam. Barley, cotton, lettuce, and sorghum were grown in rotation for 14 years. Soil irrigated with only wastewater and no additional fertilizer was compared with soil irrigated with well water and fertilized with suggested amounts of nitrogen, phosphorus, and potassium. Soil irrigated with wastewater had a lower infiltration rate, higher modulus of rupture, and more soluble salts, nitrates, and phosphates than did soil irrigated with well water. Irrigation with wastewater for 14 years did not decrease field crops yields or result in any adverse effects on Grabe silt loam soil that could not be corrected with minor changes in field crop culture.

What Is Not Known

Maximum and Optimum Wastewater Irrigation Loads

The maximum amount of treated municipal wastewater that may be applied to a given soil on which a specific crop is being grown is not known. The acceptable load is usually determined by the quantity of wastewater that can be used beneficially by a crop or by the amount of fertilizer nutrients that can be assimilated by a crop without detrimental effects. Nitrogen is usually the nutrient that limits the amount of wastewater that can be used. Excessive nitrate concentration in groundwater may occur as a result of overloading an irrigation system. Past experience has shown that acceptable loadings range from two to seven acre-feet of wastewater per year. Elemental nitrogen requirements for crop plants generally range from 50 to 200 pounds per acre annually. The wastewater irrigation load should be determined by the irrigation needs and/ or the amount of plant nutrients that can be utilized by the crops to be grown. The elemental nitrogen content of treated municipal wastewater ranges from 50 to 80 pounds per acre-foot.

Regulation of Wastewater Supply and Demand

Effective systems for the regulation of wastewater supply and demand have not been developed. The continuous supply of municipal wastewater throughout the year must be stored and adjusted to the needs of the crop plants to be grown in ways that will prevent the pollution of underground water supplies. The regulation of wastewater supply and demand will be more difficult in the northern, humid regions than it will be in southeastern and southwestern regions where cropping systems can be developed that will use some wastewater throughout the year.

Effects of Wastewater on Soil Properties

Effects of continued use of municipal wastewater on specific physical, chemical, and biological properties of soil have not been thoroughly investigated. For example, how does the continued use of wastewater influence the nitrification rate, the mineralization rate, and the mobility of phosphorus in the soil? Do the biological effects of wastewater influence the physical properties of soil and are some detrimental effects balanced by beneficial effects?

Effects of Wastewater on Crop Yield and Quality

Effects of continued use of wastewater on yield and specific bio-chemical quality characteristics of crop plants for human food and livestock feed are not known. Yields and quality characteristics will vary for different crops, cropping sequences, and rotations. The fiber, protein, amino acid, and digestible nutrient content in plant materials determine their relative food and/ or feed value.

Effects of Wastewater on Crop Variety

Adapted varieties of crop plants for continuous irrigation with municipal wastewater are not known, and have not been developed. New varieties of all crop plants may have to be developed for the most economical and efficient utilization of wastewater in agriculture.

Future Research Suggestions

Maximum and Optimum Wastewater Irrigation Loads

Research should be conducted to determine the maximum and optimum treated municipal wastewater irrigation loads for different soil types and different crop plants.

Regulation of Wastewater Supply and Demand

Effective systems for the regulation of municipal wastewater supply and demand in specific areas and for specific soils and specific crop plants need to be developed.

Effects of Wastewater on Soil Properties

Studies to determine the effects of continued use of municipal wastewater on specific physical, chemical, and biological properties of soil are needed.

Effects of Wastewater on Crop Yield and Quality

The effects of continued use of municipal wastewater on yield and specific biochemical quality characteristics of crop plants for human food and livestock feed should be determined.

Crop Varieties for Wastewater Culture

Adapted varieties of crop plants for continuous irrigation with municipal wastewater should be developed, using plant breeding techniques, for efficient and economical utilization of wastewater in agriculture.

SUMMARY

It is imperative that representatives from the United States Environmental Protection Agency, the United States Department of Agriculture, and the National System of Land Grant Universities develop cooperative and coordinated research programs that will lead to the best possible recycling of municipal effluents and sludges to the land. There are instances where wastewater from municipal and/ or industrial sewage plants was dumped into rivers and streams and allowed to pollute these streams and in some cases to pollute the underground water supply. This discarded wastewater has a built-in agricultural potential that can be used in the production of food and feed from crops like corn and sorghum, high quality forage from crops like alfalfa, special oils from crops like safflower, and high quality fiber from crops like cotton. Although numerous discarded materials in our society are considered wastes today, many of these materials can be effectively utilized in the days ahead to provide the variety of foods needed to feed our hungry world.

ACKNOWLEDGEMENTS

This report briefly summarizes past research on the utilization of treated municipal wastewater as a

source of irrigation water and plant nutrients in agriculture. Only a few of the many contributors in the field of wastewater research have been included in the references listed in this report. To these contributors who have been cited and to all others who have contributed to wastewater research in any way and are not mentioned, I am deeply grateful.

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DISCUSSION

QUESTION: John Walker, USDA, Beltsville. You said that when you irrigated with effluent you had a yield, I think it was of oats, that was much greater than when you gave it chemical fertilizer and nutrients and you didn't speculate as to why that was. Why would that be? Do you know?

ANSWER: A number of reasons have been suggested for this. We at the University of Arizona are not in 100 percent agreement by any means as to how we should answer a question like that. We do feel that there are a number of constituents in wastewater that we don't very often talk too much about that probably have something to do with the response that we received.

COMMENT: Al L. Page, University of California. In response to the last comment regarding what this could be due to. It very well could be due to trace elements in the effluent as opposed to the lack of trace elements in the irrigation water.

QUESTION: Darwin Wright, EPA. I would like to ask Bill Sopper if he saw the same response in his forests and I was wondering if this is it due to the nutrients or whatever is in the sewerage or sludge or is it due to the water itself?

ANSWER: I think it would just be both.

QUESTION: Jim Evans, USDA, Washington, D. C. I believe that you made a statement that in applying sewerage effluent versus applying the irrigation water and N-P-K, that you got a higher quality food product, higher quality bread from the fertilizer. Is this correct?

ANSWER: Yes, this is correct.

QUESTION: Jim Evans, USDA. Would you speculate as to why this is true?

ANSWER: One thing that was noted was that in other numbered characteristics that go together that they call milling quality. There are a number of things that the miller does that he uses to determine whether or not wheat A has what he would call good, medium or poor milling quality versus say wheat B and so on. So, as far as the general milling quality was concerned, that wheat that was grown with regular irrigation water and fertilized with N-P-K from commercial sources, rated higher as far as general milling qualities are concerned was that the cookie diameter in some cases was a little greater when well water and commercial forms of N-P-K was used than when wastewater alone was used. In another instance I can think of, I believe, the general loaf volume was a little larger, a loaf was a little fluffier using conventional culture over wastewater alone.

QUESTION: Jim Evans, USDA. Were these significant differences?

ANSWER: In some cases they were. There were some instances when they were not. I would have to go back to the details. I would be glad to give them to you if you want to see me afterwards or write me, but in most cases they were real differences.

Engineering and Economics of Sludge Handling

W. J. BAUER
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INTRODUCTION

Sludges resulting from treatment of municipal sewage are difficult to dewater so that transportation and application problems begin with considerations of just how much effort to expend on dewatering. With a view to stimulating the thinking of engineers concerned with the constructive use of this valuable resource, this discussion is presented by a practicing engineer who has been closely involved in excavating and transporting over one million wet tons, and in applying to land over a half million wet tons of sludge slurry from the Metropolitan Sanitary District of Greater Chicago. The sludge was transported by unit train for distances up to 170 miles from Chicago. Application was performed by several different techniques, as will be discussed herein. Alternative transportation systems are also discussed, including truck, rail, barge, and pipeline.

Types of Sludges; Physical Characteristics

Sludges can be primary or secondary, digested or undigested, or various combinations. Although their chemical and physical characteristics vary widely, for purposes of this paper these variations will be ignored.

The undigested sludges generally call for minimizing exposure of the sludge to reduce the possibility of anyone being offended or believing that he has been offended by an odor. Because of the widespread belief that all sludges do have an odor, it is also generally a good idea to handle digested sludges in the same manner. For that reason, the methods of sludge application which provide the least visibility of the sludge itself are recommended as the preferred practice.

The differences between sludges are sufficiently marked to warrant tests of both chemical and physical properties before final design of the handling facilities. The chemical characteristics are being dealt with by others at this workshop, so I shall confine my comments to the physical characteristics which affect transportation and application costs.

Costs of Dewatering

Sludges to be handled have solids contents ranging from 1 to 100 percent, the latter being heat dried sludges. The costs of dewatering vary widely depending upon the particular sludge and technique being used, but some generalizations will be made to illustrate basic concepts of how the desirable per cent solids for a given situation can be analyzed.

The following fundamental assumptions will be made regarding costs of dewatering:

Method	*Resulting percent solids*	*Dewatering Cost/dry ton*
Lagoons, including excavation	15%	$15
Vacuum filter, including exc.	25%	22
Centrifuge	30%	20
Filter press	40%	30
Vacuum filter + heat drying	99%	100
Lagoons, without excavation	25%	5
Vacuum filter, without exc.	25%	16

The actual costs for these processes vary considerably with the particular situation which pertains to a given case, and should be specifically determined for that case. The figures given above are merely to be used in this paper in the examples given to illustrate the alternatives to be examined in designing transportation and application systems.

Hydraulic Characteristics

The hydraulic characteristics of sludges vary considerably also with the percent solids. Figure 1 illustrates the variation of the apparent Darcy "f" as a function of percent solids for a given temperature, grease content, entrained air contents, etc., but for the sake of simplicity, we shall in this paper use the simple curves of Figure 1 as guidelines for the illustrative examples given. Sludge (A) is a hypothetical example of a secondary sludge, and Sludge (B) is a hypothetical example of a primary sludge.

It can be noted that below a concentration of about eight percent solids the sludges behave as fluids with an apparent "f" of .02 to 0.04. Sludges with 12 to 18 percent solids can be pumped, but with substantially higher apparent friction factors, ranging up to, say, f = 0.20 as a practical upper limit, except for extremely short distances.

These hydraulic characteristics would be measured in the laboratory for any one sludge and the results used in evaluating alternative systems.

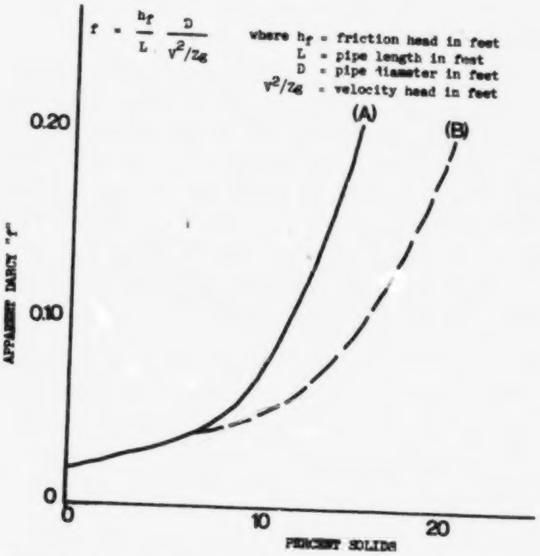

Figure 1: Illustrative Diagram for Two *Hypothetical* Sludges

Alternative Transportation Systems

Pipeline

Pipeline costs are roughly proportional to the distance transported. Double the distance and you double the cost. This is not true with some of the alternative forms of transportation, and therefore this important difference must be kept in mind.

Pipeline costs depend a great deal on the type and permanence of the pipe used. In the work of Soil Enrichment Materials Corporation light-weight quick-coupled pipelines have been laid over the surface of the ground for contracts lasting one or two years. Such lines are low in first cost, but the entire cost of the line must be written off over the duration of the contract of which they are a part. For example, a four-mile pipeline 12 inches in diameter was used for one such project. The capital cost of the line and pumps was approximately $200,000 installed. It was used to move sludge for the warm months of the year over a two-year period. The typical rate of flow was 1.5 MGD of five percent solids sludge, for a daily movement of 300 dry tons With 100 operating days in each of two years, a total of 60,000 dry tons could have been moved. (The actual contract quantity was somewhat less than this amount so the full opportunity to use the pipeline did not materialize.) The capital cost would have then been about $3.33 per dry ton, or, say, 83c per dry ton mile. To this an operating cost would be added for, say, a rough estimating total cost of one dollar per dry ton mile. For a permanent pipeline written off over a period of about 20 years the capital, plus operating cost is estimated to be approximately $11.30 per dry ton for a distance of 66 miles* . This works out to be about 17¢ per dry ton mile. The figure did not vary greatly with changes in percent solids over a range of four to seven percent. Table 1 summarizes the analysis.

Truck Transportation

For purposes of this paper, the cost of the truck transportation may be taken to be ten cents per wet ton mile, including loading costs. The cost per dry ton mile will then depend upon the percent solids handled. Trucks can be designed to handle any percent solids.

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* "Land Reclamation Project", Metropolitan Sanitary District of Greater Chicago, 1967, Harza Engineering Co., Bauer Engineering, Inc.

TABLE 1
Calculation of Pipeline Transportation Costs

Item	*Site 1*	*Site 2*	*Site 3*	*Site 4*
Pipeline length	65 miles	57 miles	66 miles	35 miles
Capital Cost (67)	$20.7 million	$18.5 million	$19.7 million	$12.7 million
Capital Cost (73)	41.4 ''	37.0 ''	39.4 ''	25.4 ''
Annual Capital Cost, 6%, 20 yrs	3.73 ''	3.33 ''	3.53 ''	2.29 ''
Annual Operating Cost, energy	.08 ''	0.08 ''	0.08 ''	.06 ''
Annual Operating Cost, other	0.52 ''	0.52 ''	0.52 ''	.52 ''
Total Annual Cost	4.33 ''	3.93 ''	4.13 ''	2.87 ''
Dry tons/ year	365,000	365,000	365,000	365,000
$/ dry ton	$12.10	$10.80	$11.30	$ 7.90
$/ dry ton miles	0.187	0.189	0.172	0.225

(Based on Table G-1, 1967 "Land Reclamation Project" report by Harza Engineering Co. and Bauer Engineering, Inc. to Metropolitan Sanitary District of Greater Chicago.)

Barge Transportation

For purposes of this paper, the cost of barge transportation will be taken as $1.50 per wet ton for distances of 100 miles, and $2.00 per wet ton for distances of 200 miles, including loading costs. Again the cost per dry ton depends upon the percent solids which can be handled. The cost of unloading barges is very much a function of the ingenuity of the designer, but because covered barges would in all probability be required, it is conservative to assume that the material would be handled in the slurry form, and (with present practice) the percent solids would probably not be greater that eight percent, with six percent being a more commonly attained figure.

Rail Transportation

Tank cars are the most commonly used carriers for sludge at present. Unit trains of up to 40 cars at 85 tons each have been operated by Soil Enrichment Materials Corporation, with 24-hour turn around having been achieved as a steady practice for one-way hauls of up to 170 miles. Under these conditions, the cost of the rail transportation, including tank cars is estimated to be, roughly, 1.2¢ per wet ton mile, including loading costs. For larger distances and larger unit trains the cost would be more. (Note that this figure does not include excavation of sludge from lagoons, pumping from lagoons to tank cars, and application to land.)

Again the cost per dry ton depends upon the percent solids. Tank cars have been used successfully with 12 percent solids sludge of a digested secondary type. With primary sludges, 15 percent solids can be handled successfully. The cars are equipped with agitators to permit draining of these thick sludges from the cars in a reasonable period of time.

Alternative Application Systems

The following alternative application systems have been used for sludge applied to agricultural land:

1. Direct dumping of filter cake from truck, followed by spreading and plowing into the soil.
2. Direct dumping of slurry from truck, followed by plowing into the soil.
3. Flooding of prepared leveled ground from pipelines, and later plowing of the dried sludge into the soil.
4. Irrigation of slurry using high pressure nozzles.

5. Plowing in of a slurry fed continuously through a hose to a moving plow.

The latter system is the one presently preferred by SEMCO, for the following reasons:

a) It is a one step method. There is no need to return to the site to plow the sludge in later.

b) It allows the material to be handled entirely in closed containers. Lack of visibility to the general public reduces aesthetic objections, even though there may be no odor problems.

c) If there are any odor problems, even intermittent ones, this method eliminates any adverse effects on neighbors.

I have had considerable involvement with methods 4 and 5 preceding, and the preference for method 5 is based upon that experience for rather large volumes of sludge handled on a continuous long-term basis. I have also had experience with smaller quantities of sludge being applied with methods 1 and 2, and have found these methods acceptable for smaller quantities, such as less than 50,000 wet tons of sludge at one site for one season. For the sake of illustrating the economic significance of the various *combinations* of systems without getting into the benefits of particular techniques of application, we shall use the cost figure of $20 per dry ton for each of these application methods; this includes the unloading costs from the transportation system. It is beyond the scope of this paper to discuss the advantages and disadvantages of each of these methods, so that this uniform cost figure will be used even though it is of course only a hypothetical situation.

Excavation from Lagoons

The lagooning process, though it is an economical method for the concentration of sludges, involves the later step of reclaiming or excavating the sludge from the lagoon. By contrast, a method for dewatering which can be a part of a continuous flow sheet eliminates the expense of this excavation. For purposes of making cost comparisons here, the lagooning step will be assumed to require the additional expense of later excavation, and this will be taken to cost ten dollars per dry ton, making a total of $15 per dry ton for this method.

Comparison of Costs

Comparisons of the hypothetical costs of handling sludge from a large city are given in Table 2. It must be remembered that these hypothetical illustrations are given simply for the purpose of furnishing examples which can be discussed here. Actual costs would depend materially on the conditions peculiar to each problem.

Alternative 1

This uses a lagooning at the site of the treatment plant, followed by later trucking at 15 percent solids to a site 20 miles distant, followed by dumping at this site and later plowing into the ground. The transportation cost of ten cents per ton mile for a distance of 20 miles results in a cost of $2.00 per wet ton. Dividing by 15 percent solids gives the $13.30 per dry ton listed in the table for transportation.

Alternative 2

This is comparable to the operation of Alternative 1, except that rail haul for a distance of 100 miles is used. The material is hauled at 15 percent solids, with a freight cost of $1.20 per ton for the 100 miles. Dividing by the percent solids gives the eight dollars per dry ton figure listed.

Alternative 3

Vacuum filtration is used to develop a 25 percent solids condition and then the material is hauled 20 miles by truck. The transportation cost of 10¢ x 20 miles = $2.00 per wet ton is divided by 25 percent solids to obtain the $8.00 per dry ton transportation cost listed in the table.

Alternative 4

A portion of the sludge is concentrated by vacuum filtration and then mixed with the unconcentrated balance of the sludge to produce a 15 percent solids material. The cost is calculated for the filtration of 55 percent to be 0.55 x $16 = $8.80 per dry ton. This was rounded off to nine dollars, allowing a small amount for mixing with the remaining 45 percent of the material which would be at about three percent solids. The resulting mixture is then 0.55 x 0.25 + 0.45 x 0.03 = 0.1375 + 0.0135 = 0.1510 or, roughly, 15 percent solids. The transportation cost of $1.20 per wet ton divided by the 15 percent solids gives the eight dollars per dry ton transportation cost listed.

Alternative 5

A 20-mile pipeline is used with the sludge as produced at the plant and thickened somewhat to, say, five percent solids. This can be pumped easily without high friction factors. The cost of the thickening to five percent was ignored in the comparison, as it would be small. The pipeline is written off over a period of 20 years which results in 17¢ per dry ton mile cost, or $3.40 for the 20 miles.

Alternative 6

This is the same as Alternative 5, except that the length of the pipeline is increased by 100 miles.

Alternative 7

A vacuum filtration of a portion of the sludge is used as before, followed by mixing with the unconcentrated sludge to effect an eight percent dry solids content which can be handled in a barge. The corresponding cost of dewatering is of course low, but the transportation cost of $1.50 per wet ton divided by the three percent solids gives $18.75 per dry ton transportation cost, which is seen to be relatively high.

TABLE 2
Comparison of Alternative Methods for Handling Secondary Sludge from a Large City

System Description	*Dewatering Cost*	*Transportation Cost*	*Application Cost*	*Total Cost*
		Dollars Per Dry Ton		
1. Lagooning and later excavation, then trucking to site 20 miles distant, where it is dumped and later plowed into the soil at 15% solids	$15	$13.30	$20.00	$48.30
2. Lagooning and later excavation, then 100 miles rail haul to site at 15% solids, then dilution and plowing into soil at 10% solids	15	8.00	20.00	43.00
3. Vacuum filtration to 25% solids, then truck haul to site 20 miles distant, where it is dumped and later plowed into the soil at 25% solids	16	8.00	20.00	44.00
4. Vacuum filtration of 55% to 25% solids, then mixing with remaining 45% of sludge at 3%, 100-miles rail transportation at 15% solids, then dilution and plowing in at 10% solids	9	8.00	20.00	37.00
5. Pipelining for 20 years at 5% solids for 20 miles, then lagooning, later excavation and plow application at 10% solids	15	3.40	20.00	38.40
6. Same as 5, except for 100 miles	15	17.00	20.00	52.00
7. 100-mile barging of 8.0% material after vacuum filtration of 20% of total and mixing with remaining 80%, followed by application to land	3.50	18.75	20.00	42.25

Discussion of Alternatives

One of the main points of this paper is to point up the great number of possible combinations of sludge transportation and application schemes which can be developed. This paper by no means exhausts the possibilities, but it does suggest the significance of considering the many possibilities which may be available.

First of all, the range of costs from $37 to $52 per dry ton is seen to be relatively small. These costs are also seen to be competitive with incineration. Unfortunately, open competition between incineration and transportation and land application as outlined in this paper is usually not permitted. Much of the reason for the lack of open competition is the present policy of the federal government to share in the capital cost of systems, but not in the operating cost. The transportation and land application systems are usually low in capital cost, and relatively more expensive in operating cost than would be the incinerators as long as the incinerators would not require repair. Once the initial incinerators require substantial repair and maintenance, and federal funds are not available for this purpose, then the transportation and land application is free to compete with the alternative of incineration.

Secondly, it is significant to note the wide range in transportation costs when viewed separately. Note that the most expensive is barge transportation, a fact at odds with most commonly held opinions. The reason is the assumption that barges would be used with eight percent solids material, which is a solids content that permits the materials to be removed from the barge as a fluid. The requirement that covered barges be used for sludge transportation tends to work against barging of material with a higher solids content. In the case of the railroad tank car a much higher solids content can be handled as the contents can be agitated with air and the tank car pressurized to force out the material as a thick slurry. It can then be diluted, if desired, for subsequent land application.

Although all application costs were assumed to be equal, this is of course not usually the case. For example, it is unlikely that a barge unloading site would be adjacent to the sludge application site. On the other hand, the trucks can usually go very close to the site of the application. Railroads are more likely to be closer to the application site than barges, but perhaps less close than would trucks. Mitigating against the use of trucks is the farmer's opposition to compaction of the soil by excessive truck traffic over his tillable land. All of these factors would be taken into account in any actual case.

SUMMARY

One purpose of this paper is to illustrate some of the many possible combinations of sludge transportation and application which may be suitable to a given problem.

Another purpose is to show the competitive nature of the various alternative systems, and to demonstrate that open and competitive bidding which would permit a land application system to be considered as an alternative to incineration could result in substantial savings in cost, and also make use of the organic portion of the sludge as a resource.

The benefits to the soil from the use of sludge for enrichment have not been discussed, as these matters are the subject of other papers of this workshop.

One final comment to provide a perspective: A cost of $50 per dry ton of sludge for disposal corresponds to less than two dollars per capita per year, as the sludge from roughly 30 persons amounts to about one dry ton per year. Possible differences in cost arising from alternative systems are even smaller. It appears that considerations other than cost should determine the best use of this resource rich in organic material.

DISCUSSION

QUESTION: Ken Dotson, EPA, Ohio. How have you determined that the toxicity from these high applications was caused by phosphate? It seems like that at that rate of application there are a lot of possibilities.

ANSWER: Well, I really didn't determine that. I think we ought to ask Tom Hinesly. He was the guy that suggested that idea. Tom did you hear that question? Mr. Dotson asked me how I determined that the decrease in yield with the high application rates with soybeans was due to phosphorous, and I told him I got that idea from you, so maybe you could answer his question. We had these very high loadings up to 180 dry tons per acre and got a drop in the soybeans yield and Ithink you observed something of the same sort in your higher application rates.

ANSWER: Tom Hinesly, Office of the Undersecretary of the Army. Yes, on some of our experimental plots at Joliet we did have typical phosphorous toxicity. The phosphorous contents were about what they were in some studies that Dr. Toby Kertz in our department had carried on, and so we feel fairly competent that this was a phosphorous toxicity.

QUESTION: John Walker. It seems that this is an ideal opportunity for persons to get together in this project and follow what is happening, because here you have someone applying sludges up to 160 or more dry tons per acre and you have such questions—the statement was made earlier that you have phosphate toxicity and then there was another statement that you didn't have appreciable differences in uptake of metals you are probably using Chicago sludge, is that right? Right. So, this is an opportunity it seems, to really follow this. I hope that perhaps this is being done because experiences in other places and other soils would suggest that you might indeed get very high uptakes of metals. I would hope to see that in this particular study that a person would cover a sensitive crop and a non-sensitive crop and look at the sludges and identify it well enough so that a person does not draw the wrong conclusions from the results of the experiment. They might come up and say, well, you can apply this technique in some other place.

ANSWER: Of course we recognize that some crops are much more sensitive than others and we don't plan to grow Swiss chard for example. Soybean and corn are the normal crops. The phosphate toxicity we expected to disappear with time through the reversion process. In the meantime, we are going to grow corn which is not affected, but I appreciate your suggestion that some sensitive crops be grown. I think we ought to do that and we do have some test areas where this could be done, and I will take your suggestion to heart and we will see what we can arrange. Maybe you could suggest some crops.

Recycling Municipal Sludges and Effluents On Land

T. C. WILLIAMS
Williams and Works

ABSTRACT

Briefly describes pretreatment considerations, energy requirements and cost of operation of various schemes involving land treatment designed by Williams & Works. Lists twelve rather specific areas where research would be most helpful to the design engineer.

INTRODUCTION

This morning, Dr. Erickson mentioned one community in Michigan that had had some real problems with land treatment of effluent. This was an expensive error. It was not a Williams & Works project, fortunately for us. We have, however, had some minor problems. We prefer to call them "fascinating failures" rather than "expensive errors." Michigan has built more, and is building more, land treatment schemes than any other state at the present time. We are bound to have problems. We do not claim that we have perfection. We're sort of like the chap at church. The minister was giving a sermon on the relative state of imperfection of man, and he got a little carried away and said, "I am not perfect, I'm sure no one in the congregation thinks they are perfect. Anyone in the congregation think you're perfect?" Lo and behold, one chap stood up, and he said, "You mean to say you think you're perfect?" The fellow said, "No, I'm standing up for my wife's first husband."

Our land treatment schemes have not reached that state of perfection of the wife's first husband, we have problems and we admit that we have problems. Neither are the other methods of wastewater treatment perfect. An example is an actinomyces infection of the activated sludge plant at Ann Arbor. They have a tremendous carry-over of solids on occasion—they have problems. Everybody has problems. It's just that when there's something different from that which is being done commonly that we receive notoriety for our "fascinating failures."

Maurie Ettinger, some years ago, wrote a wonderful little paper entitled, "How to Plan an Inconsequential Research Project." He said, "the consequences of successful research in many scientific disciplines have been a series of great advances that have taxed the economic, political, social and physical resources of society. In contrast, however, the sanitary engineer has a distinguished record of earnest effort untarnished by embarrassing accomplishments."

We want to have some freedom to make some new mistakes. Let's not go on making the old ones. Let's not make acceptable, used, mistakes. Let's make some new ones. We will have an opportunity with the effluent disposal on to land to make new mistakes.

Williams & Works has had some experiences. We have some facts. But the purpose here, as I understand it, is to stir imagination, have ideas, get some inter-disciplinary give and take, get more than the civil engineer and the sanitary engineer's ideas on wastewater treatment. We need, in addition to the civil engineers and sanitary engineers, agronomists, agricultural engineers, and we need farmers. You know, really, we need farmers perhaps more than anything else. They have a way of getting things accomplished

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that our public works people, by and large, don't have. We also work with the SCS people when we're planning a project. We work with the Extension Agents in the area. These people have a tremendous fund of knowledge that should be utilized.

One other thought, before I get to some real facts, is that Barry Commoner in one of his books, "The Closing Circle", develops four laws of ecology. The fourth one is—"There's no such thing as a free lunch." In any wastewater treatment scheme, we must be aware of this law. There's no such thing as a free lunch. You pay for everything with something. It may be with dollars, it may be with social cost, it may be with environmental damage—whatever the costs may be, there are costs. You just can't use dollar figures.

Pretreatment

The degree of pretreatment required will vary depending upon the type of land treatment which you are going to use. If you are going to use spray irrigation, then you should have treatment equivalent to the treatment that you would provide if you were going to dispose of this liquid into surface water. I believe very firmly that you should, before you squirt it up in the air, give it at least as good a treatment as you would give it if you were going to dump it in the river. If you're going to do flood irrigation, then perhaps treatment of a lesser degree is satisfactory. If you're going to do grass filtration, then perhaps simple primary is adequate. But on all of these, you must consider the question of public acceptance.

We have more and more concern over public acceptance. It's mandated in the law now. We have environmental hearings. We need to concern ourselves with public acceptance. And in order to get public acceptance at least at this stage of the world, I believe that you have to be able to say the stuff that we're going to put on to the land for further treatment should be at least as good as what we were going to put into the river except, of course, for the removal of nutrients.

There are many climatological constraints on the pretreatment. We work in the northern part of the United States, and in our part of the country we do not irrigate in the winter time. We must store all of the wastewater that is generated during the winter season. We must provide a minimum of five months of storage. This is not as bad as it seems because as a part of that storage you can also get treatment. So we do provide storage for a minimum of five months and the economics work out quite well. In the southern part of the United States and in the water deficient areas, perhaps you can irrigate during the winter without excessive operating costs.

Land availability and isolation are also related to the treatment that you provide. If you're going to be out a thousand miles from nowhere, then you don't have to be so concerned about the treatment that you provide prior to the application to the land. I went to Melbourne, Australia a few years ago, and I stood out on their sewage farm at Melbourne and asked them if they had any odor problems. Oh, on occasion they did. There's a town down the road and they complain about the odor. How far away is the town? Oh, it's about twenty miles. This kind of an odor problem we couldn't stand in our area. There may be places where you can. It turns out, incidentally, that the odor problems there were from the anaerobic lagoon system, not from the land treatment system.

The processes utilized in treatment prior to irrigation are:

1. No pretreatment other than maceration - for grass filtration.
2. Primary treatment.
3. Trickling filter.
4. Activated sludge.
5. Aerated lagoons.
6. Natural or facultative lagoons.
7. Anaerobic - aerobic pond systems.

In considering any and all treatment alternatives, we ought to concern ourselves with the energy requirements. Concern over energy is a very popular subject at the moment. We use a lot of energy in wastewater, and we ought to consider this.

The City of Wyoming in Michigan has a trickling filter plant, and they have vacuum filtration of the raw sludge with incineration of the filter cake. We totalled up all of the energy input into the plant—(including the last pumping station on the collection system) this is the electrical energy, the gas and oil, all of the purchased energy into that plant—and the purchased energy required was 10,000 BTU per pound of BOD removed.

Belding, Michigan has a facultative pond system and uses about 1,200 BTU per pound of BOD removed. In between that, an aerated lagoon with spray irrigation used about 4,000 BTU per pound of BOD removed. However, this last one (4,000 BTU) is a land treatment scheme and there is 100 percent BOD removal as opposed to the smaller percents in the other facilities.

Methods of Land Application

I will just list some of the systems we have used for spray irrigation:

1. Center pivot machines.
2. Winched pulled guns that travel back and forth across the field.

3. Portable aluminum pipe systems.
4. Solid set systems.

We are now of a mind that we will probably not design any more spray irrigation systems using anything other than solid set systems. We find that for an operating facility in the small communities that we deal with, most of our clientele are towns of 10,000 and less, that in those communities we're better off with a solid set system that can be automated and maintained relatively easily as opposed to other ways of doing the job.

Flood irrigation is another method, and we have paddocks that are flattened out and dosed like the intermittent sand filters that we used to use. These are irrigated in the summer only and will be cropped. We have seepage ponds, or seepage beds, that can be loaded year around. You're not dependent upon the weather.

Grass filtration is another way. And then, of course, there's subsurface disposal. You know, there are half a million septic tanks installed each year in the United States. Presumably, they all have tile fields of some sort or another. This is sub-surface disposal, and this is a tremendous number of units. A tremendous number of dollars is spent on it, and we know relatively little about the fate of goodies that come out of these things.

Cost Effectiveness

Cost effectiveness as opposed to other treatment methods. Just in case somebody comes along with a wonderful little black box someday and we don't have to have all of these pipes running around and collecting the sewage, we can take care of it all at the point of its origin. Just in case that somebody does develop such a thing, we ought to look at the reclaim value of the facilities used for wastewater treatment. If we're using land as a part of the treatment project, the land retains its value and, in fact, its value is enhanced.

We can grow crops. We do not believe that you should anticipate a profit from crops in your planning of the financing for a project. We believe that you should plan on the cropping being at best a breakeven proposition.

There are, also, advantages in terms of green belt development.

There are advantages in terms of recreational areas. Working in deer country, we have found that when you clean a piece of land off and use it for land treatment, you provide an environment that is better for deer than a forest. We have one pond and irrigation scheme where we have a snowmobile trail around the pond. They have races there. It's all organized and run by the Chamber of Commerce—a very good utilization of that extra land that you have to provide for isolation purposes. There are lots of other recreational benefits.

We had an idea the other day that if we took the wastewater before it went into the irrigation scheme and put a little aerator in it and grew fish year around, we could then build a cat food plant which would give the little community an industry that they don't have now. You can grow fish faster than you can harvest them, and take the fish out and use them to make cat food. This would be an interesting proposition.

Operation and Maintenance Costs

As I have said on other occasions, in all this program for pollution control that we have at a national level, our goal is not to build wastewater treatment facilities but to control pollution. And, if we can't get good operation of the facility, good maintenance of the facility, we are not going to achieve the goal no matter how fancy a facility we build. No matter how we design it, we're not going to come out right if we don't assure ourselves of good operation and maintenance.

Let's talk about a two-tenths million gallons a day plant - 0.2 MGD. This is a small town - 2,000 people where 80 percent phosphorus removal is required. An activated sludge plant costs $28 per capita to run—just to run the thing. A trickling filter plant costs $20 per capita; and an aerated pond with chemical precipitation of the effluent is $13 per capita. An aerated pond with irrigation of the effluent is $8 per capita, and a facultative pond with irrigation of the effluent is $6 per capita. Now to the people in that small community, this is a per capita cost; so, you must multiply it by three for the cost per household. There is quite a significant difference in the number of dollars that they have to pay for operation and maintenance of a wastewater treatment facility. As you increase the size of the facility, the costs get closer together. At two million gallons a day, the cost of operation and maintenance is about $8 for the activated sludge and $2.50 for the facultative pond and irrigation system.

Research Needs

I have twelve things that occurred to me regarding areas of research.

1. Air pollution. People are concerned about viruses and the bacteria flying through the air when we spray irrigate. I just saw a study the other day about air pollution around an activated sludge plant, and there's a problem that no one has addressed themselves to very effectively.

We ought to make some comparisons with the alternatives.

2. Inflow and outflow quality comparison on mature pond systems. There are a lot of existing pond systems, and we ought to have better data on the inflow and outflow characteristics. We have one five cell pond system and one four cell pond system. They have an anaerobic cell as the first unit, and then facultative cells following. In the one system, we have 350 days of storage at the present flow, and in the winter we get about 2/10ths of a part of phosphorus - 2/10ths or something like this of nitrogen out from under the ice. That's an interesting thing. Maybe we need to build our pond systems bigger and not put the effluent on the land because we're making such a high quality product that we don't need to.
3. Another area that we ought to look at is the quality of the ice that grows on a pond. As it freezes, the ice on the top probably is pretty good ice. Maybe if we could do some sampling—I haven't done it yet—of this ice and then if it's good stuff, harvest it and throw it in the river, leaving the goodies behind. Maybe then we'd only have half as much water to get rid of come spring.
4. Muck and peat soils. There's some work being done by the Forest Service and more needs to be done on irrigation, using muck and peat soils.
5. Swamp irrigation. There is a project under way for irrigating a relatively infertile swamp. It's being funded by the National Science Foundation. We're going to study the eco-system in the swamp and then put some treated effluent into it and see if we can increase the number of ducklings per acre from the swamp.
6. Entomology. We have a problem with bugs around the pond and irrigation areas - midges. We're doing some work, with EPA money, at Belding, Michigan on the entomology and the problems of these midges.
7. Animals. We need more information on the safety of feeding beef cattle and so on. In Michigan, we have a running debate as to whether we can feed cattle with the hay that we harvest off an irrigation area.
8. We need some thermal studies. As this stuff comes out of a pond, the pond is warm. The water goes down to the ground and becomes a part of the groundwater table, but it lays on top. There isn't any thermal mixing. We need to check and find out a little bit about this. Maybe it scoots right along the top and comes into a lake and then because of the temperature differential, there's an increase in the vegetation in the lake because of the treated wastewater. There's no problem with nutrients, but there is a problem with the increase in vegetation because of temperature increase.
9. Movement of groundwater in the unsaturated zone. Horizontal permeabilities are generally greater than vertical permeabilities. Is the path of water vertical in the unsaturated zone or is there some spread? If so, how much? We need to know to develop maximum phosphorus loading computations.
10. Pond recirculation. We had some information from Israel the other day that indicated that if we had an anaerobic cell and if we took the effluent and ran it back through the anaerobic cell, we would get much better nitrogen removal because of this recirculation through the anaerobic cell.
11. Dissolved oxygen in the effluent. Does it make a difference how much dissolved oxygen we have in the effluent in relation to the need for the 5 ft. aerated zone before you come to the water table?
12. And then one that I added the other day. And I wasn't being altogether facetious when I make comment about the drinking water treatment, that perhaps we ought to look at this whole thing as a system—the water supply and the wastewater treatment, because maybe you can give the people a better quality of water to use as drinking water, washing water and so on. As a result of this, you have less of a problem at the other end of the pipeline. So maybe those things ought to be tied together someplace.

My closing thought . . . yesterday was experience, tomorrow is hope and today is getting from one to the other as fast as we can.

DISCUSSION

DISCUSSION: George Ward; Portland, Oregon. A month or two ago you and I wrestled this matter of septic tank effluent and I am glad you did bring it up in that it is seldom discussed at these conferences. We get carried away with the big plants and big problems. We found that there are about somewhere near eleven million spetic tanks in service, and for every half-million that comes on, there are probably less than a half-million taken off the line. We are not even holding our own. Every time one goes out of service, two pop up. That doesn't mean that the tank is bad. In theory the discharge fields, I think are what you meant to chastise. But at your recommendation, we did contact a Mr. Cecil Rose with the Farm and Home Administration in Washington and I also met someone from Sweden with some ideas on what they are doing. And it is interesting to note, that I think most of us assumed that if you have a septic tank, you use the conventional procedure. It is not necessarily true, in that you can use the septic tank not only as a solids interceptor and by the addition of one or two more just quieting tanks, relatively small, and also the draw of tubes from one tank to the next. You are going to prevent solids carry over, and then you are dealing with just anaerobic effluent reasonably free of solids. Then you don't have to quit. It is an easy matter to take some rather inexpensive plastic type, what FHA calls a variable gradient pipeline, just a PVC tube bearing. You can then pump it some distance away from your source, put it into aerated lagoons or do whatever you want to it. So, my point, was that I don't think it was your intent to chastise the septic tank. I think in your closing remarks where you suggested imagination, we should probably apply some there and what to do with the enemies that come out of those third tanks.

CHAIRMAN: Do you want to respond to that Ted?

ANSWER: Ted Williams, Michigan. I suppose I should. I am not real sure what I should say. There are many places where septic tank and tile field systems properly designed and properly maintained are a viable alternative to public sewerage systems. Many times we are in the situation where we go around and say, "Oh, look at all those septic tanks" and the terrible problem or the potential for a terrible problem and we have to get rid of them. We can't allow this property to develop on septic tanks and tile fields. So we select it all together and then we remove 80 percent of the goodies and dump it in a creek. Well, you might better have left it in the land in the original case, if the soils are right and if the design is proper. But, like all of these systems that we are talking about, all of the alternatives that we consider, it is a matter of design: proper, good design and good management. These are the important considerations and in some places one is best and in some places another is best.

CHAIRMAN: I might add one point to that. Under the new Public Lw 92-500, The Federal Water Quality Act Amendments of 1972, EPA is charged with developing or reviewing the whole septic tank problem. We call it rural waste. And so if any of you have any ideas, good ones, we would be interested in hearing from you.

Economic Aspects of the Application of Municipal Wastes to Agricultural Land

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ABSTRACT

The implications of minimizing the cost of waste treatment and of its disposal on agricultural land are presented. In the process of cost-minimization account is taken of crop returns from application of waste and of environmental damage. The optimal rate of application of waste to crops is shown, in principle, to be influenced by all variables and functions in the system, including the marginal cost of alternative methods of treatment and disposal. Research needs in the general terms of the cost-minimization model are discussed.

A simulation analysis of a particular land-reclamation sludge-disposal project is described. The variables found to be most influential in performance of the system included: transport costs for sludge, site preparation costs, assumptions regarding the nitrogen budget, choice of cropping system, and source of labor used in site preparation. It follows that research on these variables would improve decision making regarding the application of waste to crop land.

INTRODUCTION

Our assignment of considering "systems ranging from maximized productive crop utilization to maximum capacity accommodation . . ." requires that we review the economic logic of a total system of waste disposal on agricultural land. This will permit us to pinpoint more clearly the kinds of information needed for analysis of the desired balance between the multiple objectives of economic crop production, minimum-cost waste disposal, and environmental quality objectives.

In what follows we present first a simple cost-minimization model which will indicate the principal relationships within the system as we view it and thus provide a framework for indicating the relative information needs in general terms. This will be followed by a discussion of a simulation model of a land-reclamation sludge-disposal project. Sensitivity analysis will indicate the relative importance of additional information on specific variables.

Cost-Minimization Model

We use the following notation:

W_1 = quantity of waste to be applied to land in crops.

W_2 = quantity of waste for disposal by an alternative method.

W = total quantity of waste for disposal. $(W_1 + W_2 = W)$

TC_1 = cost of treating, transporting, and applying waste, W_1, to crop land.

TC_2 = cost of treating and disposing of waste, W_2, by an alternative method.

A = acres of crop land used for waste disposal.

X = quantity of resources (other than W_1 and A) used in crop production.

Y = physical quantity of crop produced.

C_a = cost per acre to gain control of land (may be rent, annual cost of purchase, annual cost of purchase and reclamation, etc.).

C_x = cost per unit of non-land and non-waste resources used in crop production.

P_y = selling price per unit of crop.

D_1 = dollars of damage (considered as a cost to

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the system) to environment caused by use of W_1 on crop land.

D_2= dollars of damage (considered as a cost to the system) to environment caused by discharge of W_2 (alternative to the disposal-on-land method of treatment and disposal).

These variables are related to each other by the following set of functions:

$Y = Y(W_1, A, X)$	Crop yield response function.	(1)
$TC_1 = TC_1(W_1)$	Cost of treating and disposing of W_1 on crop land.	(2)
$TC_2 = TC_2(W_2)$	Cost of treating and disposing of W_2.	(3)
$D_1 = D_1(W_1)$	Environmental damage function for W_1.	(4)
$D_2 = D_2(W_2)$	Environmental damage function for W_2.	(5)

Of the many institutional arrangements, we consider the one in which the two waste disposal processes and the agricultural crop operations are viewed as if they were within a single decision unit. We note that another speaker has the assignment of discussing institutional options. This decision unit wishes to minimize the total cost, including damage to the environment and any offsetting return from crops, of disposing of a given amount of waste, W. The decision unit may purchase land directly or rent land by the acre on a cash basis rather than crop-share. Preparation of the land for crop production (e.g., levelling strip-mined land) may also be included in the cost. Further, the damage to the environment by use of both (1) the land-disposal process, and (2) the alternative process must be borne by the decision unit. That is, we assume that what are usually viewed as externalities have been internalized.

The objective of the decision unit is to minimize total cost, TC, which is defined as follows:

$$TC = TC_1(W_1) + D_1(W_1) + TC_2(W_2) + D_2(W_2) - PyY(W_1, A, X) + C_aA + C_xX \qquad (6)$$

subject to $W = W_1 + W_2$ or the disposal of all waste generated by the decision unit. Minimization of TC results in the following conditions:

$$\frac{\partial TC_1}{\partial W_1} + \frac{\partial D_1}{\partial W_1} - Py\left[\frac{\partial Y}{\partial W_1}\right] = \frac{\partial TC_2}{\partial W_2} + \frac{\partial D_2}{\partial W_2} \qquad (7)$$

$$Py\left[\frac{\partial Y}{\partial A}\right] = C_a \qquad (8)$$

$$Py\left[\frac{\partial Y}{\partial X}\right] = C_x \qquad (9)$$

These three relations, 7, 8, and 9, together with $W = W_1 + W_2$ provide a solution for the four unknowns, W_1, W_2, A, and X.

Our assignment indicated that we should focus on the rate of waste application per acre, W_1 / A. It can be seen that the optimal rate depends, in principle, on all other variables and the relationships among them in the system. The degree of dependence is, of course, an empirical question. To indicate how the rate W_1 / A fits into the system, we refer first to Figure 1.

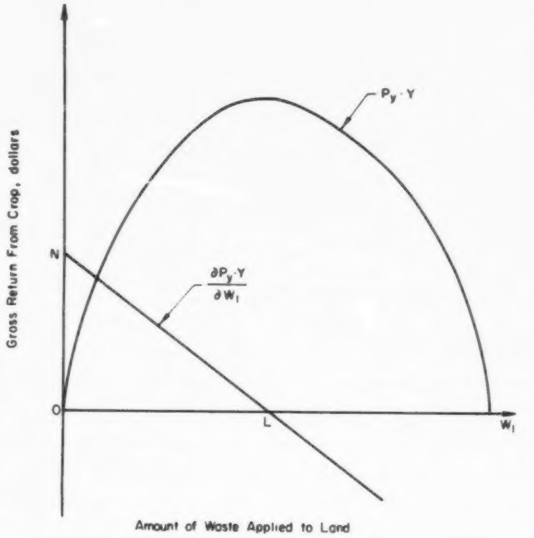


Figure 1: Gross Return and Marginal Return from Application of Waste In Crop Production.

With the price of the crop, Py, fixed, this curve has the same shape as the crop yield response curve. The marginal return, NL, indicates the addition to gross return if the waste, W_1, were costless. Note that if we were to view profitable crop production as the *sole* objective in such a situation, OL is the optimal amount of waste to apply. If W_1 is not costless, how should it be priced? To answer this, we need to go back to equation (7), one of the conditions for total cost minimization for the entire system. This condition indicates that the total marginal cost for the land disposal method (including environmental damage and return from crops) must be equal to the total marginal cost of disposal by the alternative method. In Figure 2, the left-hand side of equation (7) is graphed. For simplicity, we assume that the functions for yield response (1), total cost, TC_1, (2), and damage (4), are quadratic in W_1, thus giving linear derivatives. Line MKP represents the total marginal cost of waste disposal on crop land. As in Figure 1, OL represents the amount of waste, W_1, to be applied for maximum crop yield per acre. Suppose that the total marginal cost (treatment and disposal cost plus environmental damage) for the alternative method

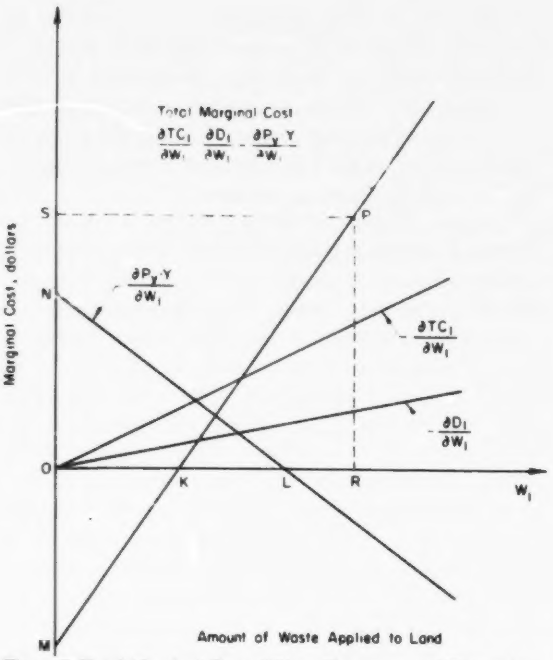


Figure 2: Total Marginal Cost of Waste Treatment and Disposal on Land.

(right-hand side of equation (7)) is OS (or RP). This would require an application rate OR in excess of maximum crop yield per acre. If the total marginal cost of the alternative method were to decrease sufficiently, the optimal application rate would drop to less than OL. Optimal application rates less than OK would mean that disposal on land created, in total, an income rather than a cost.

Of course, other variables besides the marginal cost of alternative disposal methods could affect the optimal application rate. For example, the price of the crop, Py, the rent or cost of land, C_a, etc. The marginal value product of waste (NL) also has implications for the price a farmer can afford to pay for varying amounts of waste, W_1. If crop production is viewed as a separate decision-making unit, amounts of waste less than OL, have a positive value and could command a price; applications in excess of OL would cause financial loss to the crop enterprise and would require compensation.

General Research Needs

In this section we present an assessment of broad categories of research needs. After presentation of the simulation model, the specific needs as revealed by that analysis are presented. In the cost-minimization system, the optimal rate of application of waste to cropland, W_1 / A, depends on knowledge of the functional relationships (1) through (5) and prices and costs. How much do we know about each of these relationships?

Yield Response Relations. Although in the Corn Belt a number of experiments have been conducted to estimate crop yield response to the plant nutrients[19,21], very few have made estimates of the yield response to water[16]. Fewer still have made estimates of the *joint* effects on crop yield of adding nutrients and water[4,15]. These joint effects effects are of particular importance in the application of wastewater and sludge. Further, few experiments have examined the yields past the maximum. There has previously been no economic need for interest in this zone. In summary, our estimates of the crop production relation (1) presently depend largely on informally synthesized judgments of individuals familiar with crop yield under different nutrient-moisture regimes.

Cost Functions. Relationships (2) and (3) involve basically engineering estimates and it would be expected that the parameters in these equations could be estimated with relatively greater precision than (1) which is an essentially biological relationship. If (3) refers to a conventional system of treatment and disposal, one would expect that experience on the technical relationships together with the updating of costs, would give us rather precise knowledge of this relationship.

Damage Functions. Perhaps our knowledge is most meager in the case of the damage functions, (4) and (5). Although these damages are expressed in dollars, in the case of many of the potentially harmful aspects of applications of wastewater or sludge, we do not even know the fundamental physical relationships. For example, the transformation in space and time of plant nutrients and heavy metals represent processes that are not well understood. As a result, public policy attempts to reduce the adverse environmental impact by such methods as setting standards.

Case Study: A Simulation Analysis

Background. A recently completed economic simulation study provides some indication of the type of analysis needed and begins to identify important variables and relationships requiring further study[9]. The case being studied involves the disposal of municipal sludge on reclaimed strip-mined land on a large scale basis.

The Metropolitan Sanitary District of Greater Chicago (MSD) is charged with the treatment and disposal of the sewage waste of the city, its suburbs, and its industry. One of the products of this activity is over 900 dry tons of anaerobically digested sludge per day. In the past it was lagooned, dried, or incinerated, all of which are now impractical. As a result, the MSD searched for other means of disposal, including both carrying out experimental projects and supporting organized research efforts[12, 13, 14].

Fulton County, Illinois, located 170 miles southwest of Chicago, has had over 50 thousand acres of its land area disturbed by strip mining operations, and mining continues at the rate of about 2,000 acres per year. There is considerable public pressure within the county to utilize the disturbed acreage in some useful manner, if possible to return it to row-crop production, its use prior to mining. The soils being stripped are generally of high quality. The overburden in the county is calcareous so that acid wastes are not a problem, and the establishment of a cover crop is not particularly difficult. Also, the material is free enough from large rocks to allow the operation of agricultural machinery if the slopes are sufficiently gentle.

After preliminary explorations by officials of Fulton County concerning the alternative of utilizing sludge in reclamation of spoil land and after some contact with the MSD, the MSD purchased a tract of approximately 7,000 acres. Additional land has been purchased subsequently. The general thrust of the project is that sludge will be applied on land that has been leveled and that row crops will be produced on the land. Thus it roughly conforms to the single decision-making unit described under *Cost-Minimization Model.*

Research by agronomists has indicated that pollution problems would not be a constraint in this type of operation[7,8]. Heavy metals are apparently not absorbed in the plants to levels that can be considered a problem. The constraint on the quantity of sludge applications is expected to be the nitrogen which it contains in both organic and inorganic form. A system of capturing all surface water and monitoring groundwater has been established to minimize the possibility of pollution episodes.

The Project and The Simulation Model

The disposal-reclamation project involves the shipment of sludge to Fulton County on the Illinois river by barge and piping it to one of three lagoons with a total storage capacity of over eight million cubic yards. The possibility of constructing a pipeline from Chicago to Fulton County is being considered. The stripped land is leveled so that cropping operations are possible and surrounded with berms so that all runoff can be recycled in the event of water quality problems. The sludge is pumped out of the lagoons and sprayed on the prepared sites before planting and during the growing season, weather permitting. The crops grown will probably be typical central Illinois row crops, but the zero tillage practice will likely be used to reduce runoff and minimize the need to collect rocks.

The quantity of sludge applied over the life of the project will depend on (a) the initial level of organic nitrogen in the soil; expected to be very low relative to normal soils, (b) the nitrogen removal from the soil in the form of harvested crops, and (c) the excess of nitrogen application over nitrogen removal possible while avoiding leaching problems.

In order to appraise the importance of the several variables influencing the operation of the project, a deterministic simulation, or multi-period cost and benefit accounting model, was constructed and applied with the support of the Illinois Water Resources Center. A diagram of the model is in Figure 3. The model is less sophisticated than most simulation models in that in many cases it was constructed on point estimates of the relationship between variables, rather than functions. This was necessary when the only estimates available were the initial estimates available from the MSD. As experience is gained, in this project or in others, it will be possible to substantially improve the model. At this point, however, it is possible to begin to identify the variables that are important determinants of costs and benefits to the MSD and to the county. In contrast to the cost-minimization model, indirect benefits from any increased income are also considered.

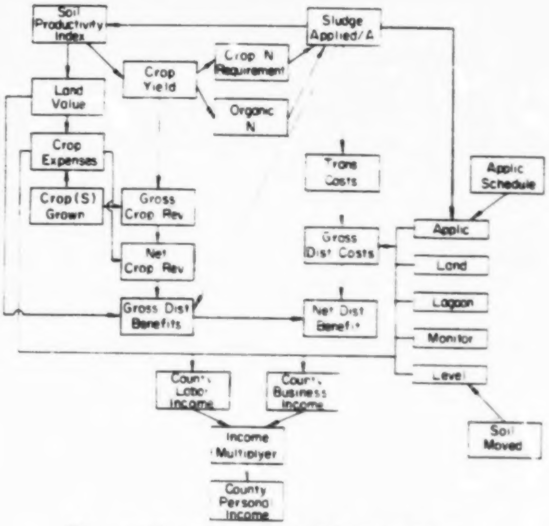


Figure 3: Flow Chart for Simulation Analysis.

The model reflects the operation of the project from transportation of the sludge from Chicago to the site, storage, handling, and application on the land. It reflects costs of leveling the land prior to application and farming which will vary over sites as well as a constant per acre cost for runoff control. The productivity of the soil is determined by sludge applied and crop residues, which in turn determines the nitrogen present in the soil. The nitrogen requirement of the crops grown is compared with nitrogen present to determine annual sludge applications possible, if any.

Crops produced and land values determine crop expenses, yields determine gross crop revenues and the difference is net crop revenue to the MSD. The increases in land values due to changes in quality and the savings over other methods of sludge disposal are added to crop revenue to determine gross MSD benefits[11]. The costs of transportation, storage, application, leveling, land purchases and monitoring are subtracted to determine net district benefits. Crop expenses and costs of operations carried out in the county determine initial county benefits, which are assumed to have a multiplier effect on county income. All costs and benefits are calculated by year over a ten to twenty year horizon and are discounted.

Results Generated

In line with the objectives of the analysis those variables that have a significant impact on the performance will be identified, roughly in order of their importance.

Transportation Costs. At present, the sludge is being shipped 170 miles to Fulton County by barge under a contract with an independent firm. If the results under this contract are compared with the results assuming construction of a pipeline prior to project initiation, a substantial difference of more than $2000 per acre over a ten-year period and over $3000 per acre over a twenty-year period are observed. While it is possible that future bids for barge transportation may be lower and the actual cost of the shipment via pipeline may be higher than estimated, the clear advantage of a pipeline is evident[13].

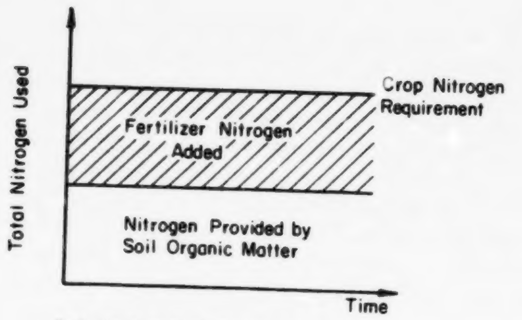
Site Preparation Costs. The costs of clearing and leveling spoil bank land as a part of any reclamation project is a subject of considerable disagreement. This project differs only in that an additional operation of constructing berms or other devices for controlling water runoff is necessary. The MSD estimates this to be a constant $300 per acre regardless of the nature of the specific site. This is added to the cost of clearing the site of brush or trees, if any are present, and of leveling. Depending on the roughness of the site, leveling and clearing is estimated to range from several hundred to several thousand dollars per acre. In the standard runs in this analysis this was assumed to be $400 (plus the $300 constant). Most of the cost estimated for leveling operations are based on experimental, one-time, projects carried out on sites of widely differing types. Over a period of years long enough to allow contractors to gain experience on the conditions found in Fulton County, the costs per acre may be reduced. That is, a learning curve may exist[3]. A trade-off also exists between the leveling of progressively rougher land on sites already owned and the purchase of additional sites that include less rough spoils but are more distant from the storage lagoons. This aspect was not included in the model.

In this model the costs of site preparation are included as first year costs to the MSD. These costs are included in county benefits, in total or in part, depending on whether local contractors and local laborers are utilized. The specification of local operators for such activities has a significant impact on the level of income generated in the county, as will be noted.

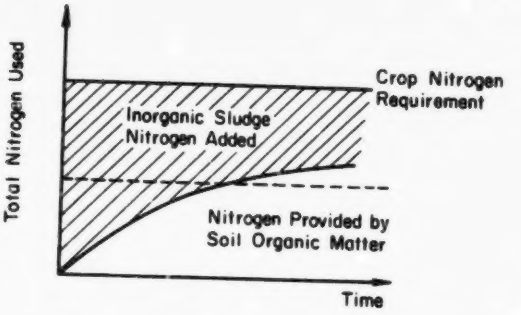
The Nitrogen Budget. The third most important factor is the quantity of nitrogen applied. If the only project objective was sludge disposal, the most efficient technique would likely be very heavy applications on a small acreage, essentially the creation of lagoons or at least areas that would have levels of water and nitrogen too high for crop production. Given the second objective, that of crop production, the sludge disposal objective could be most effectively met by operating in the third stage of the production function, that is, in excess of OL in Figure 1, in terms of water or nitrogen applied. Presumably the nitrogen limit would be reached first and operation in the third phase would imply potential nitrogen pollution problems, although the relationship between nitrogen applications on farm land and nitrogen pollution in surface water is a subject of continuing controversy[2,20].

Since research is not available demonstrating the relationships among nitrogen application, crop production, and pollution on strip-mine spoils, it was necessary to utilize the experience on normal soils which can be broken into its *stock* and *flow* aspects as suggested in Figures 4A and 4B. Normal fertile soils carry a stock of organic nitrogen, a portion of which becomes available to crops in each year through mineralization to an inorganic form which is also subject to leaching problems, Figure 4A. Strip-mine spoils have much less organic nitrogen present, in some cases it may be essentially void, point 0 on the right-hand side of Figure 4B. Over half of the nitrogen present in sludge is in organic form and therefore sludge applications will gradually build up the level of organic nitrogen in the soil, as will crop residues.

The flow aspects involve the application of inorganic nitrogen, the loss of nitrogen through volatilization, removal in the form of crops, and possible losses in the form of runoff or leaching into the groundwater. It has been estimated that on normal Illinois soils approximately 1/3 more commercial inorganic nitrogen is added than is removed by crops produced[22].


Total Nitrogen Used
Crop Nitrogen Requirement
Fertilizer Nitrogen Added
Nitrogen Provided by Soil Organic Matter
Time

(a) Undisturbed Farm Land


Total Nitrogen Used
Crop Nitrogen Requirement
Inorganic Sludge Nitrogen Added
Nitrogen Provided by Soil Organic Matter
Time

(b) Strip-Mined Land Being Reclaimed With Sludge

Figure 4: Nitrogen Supplied to Crops by Fertilizer and Organic Matter.

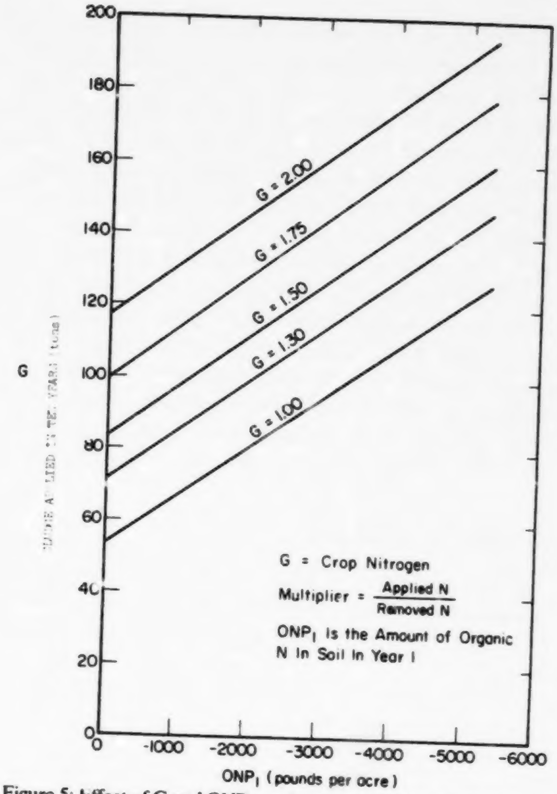


Figure 5: Effect of G and ONP_I on Amount of Sludge Applied Over Ten Years.

The potential impact of the two variables, the initial level of organic nitrogen present and the relationship between the nitrogen applied and that removed is quite significant, as indicated in Figure 5. In this figure ONP_I is the original stock of nitrogen in the first year. The ratio of N applied to N removed is denoted as G. If the original stock is assumed to equal levels present in normal fertile soil ($ONP_I = 0$) and the maximum allowable application of nitrogen is equal to that removed by the crops ($G = 1.0$), only 53 dry tons of sludge can be applied over a ten-year period. If the original stock value is zero (ONP_I = 5333 lbs.) and twice as much nitrogen can be applied as is removed by the soil ($G = 2.0$), 195 tons can be applied over ten years. Over the ranges considered, the original stock of nitrogen present is slightly more important than the relationship between annual applications and removals.

Cropping Systems. A variety of crop rotations, continuous single cropping and continuous double cropping options were analyzed. Generally systems using large amounts of sludge nitrogen are the most desirable, as is suggested in Table 1. The economic benefits from using heavier levels of sludge outweigh any differences in net revenue from cropping operations. For this reason the double cropping operations are superior to single cropping. Both of these are superior to crop rotations.

One problem with crop rotations is that the inclusion of crops with low nitrogen requirements lower the MSD benefits, as noted. But also, nitrogen pollution problems are an apparent threat with rotations. This is due to the build up of soil organic nitrogen levels through applications in the years when crops demanding high levels of inorganic nitrogen are grown. Then when crops with low nitrogen demands are grown, more nitrogen is converted from an organic to an inorganic form than is utilized by the crop. The excess may leach into the groundwater.

The cropping systems which the model suggests will perform best are: corn-rye double cropping, for grain or silage; sorghum-sudangrass; and corn single cropped. For example, almost 50 percent more sludge is applied over ten years with the corn-silage-rye system than with a corn-soybeans-wheat-alfalfa rotation.

Labor Use. The use of local labor and local contractors to perform the physical activities of the project is an important determinant of county income. Without an income multiplier (that is, a multiplier of

TABLE 1
Sludge Applied and Break-Even Alternative Disposal Costs for Ten Years of Selected Cropping Systems*

	Cumulative Sludge Applied (dry tons/acre)	*Break-Even Alternative Disposal Cost (dollars/acre)*
Double Cropping No-Tillage		
Corn (silage) with Rye	149.8	67.15
Corn (grain) with rye	148.2	67.89
Continuous Crops		
Sorghum-Sudangrass	156.7	68.23
Corn (silage)	119.9	74.82
Corn (gain)	118.2	76.03
Alfalfa	112.0	78.50
Crop Rotations		
Corn-Corn-Corn-Sorghum-Sudangrass	125.4	74.47
Corn-Corn-Corn-Corn silage	118.6	75.56
Corn-Soybeans	111.7	77.85
Corn-Sorghum-Sudan Wheat-Alfalfa	111.6	79.06
Corn-Soybeans-Wheat-Alfalfa	99.0	83.87

**Assumptions:*
ONP_1 = 3333 lbs. G = 1.3
Discount Rate = 8%
Leveling Cost = $400/ acre
Barge transportation

one), the present value of income generated in the county over ten years is [illegible] per acre when outside contractors and labor are utilized. If local labor is used by outside contractors this jumps to almost $500. If both local contractors and local labor are used, this increases to $626.

The existence of a multiplier will further increase these benefits. A multiplier of 1.11, as was estimated for Fulton County[11], would increase this to $695. If it equalled 2.0, the benefits would double from $626 to $1252.

Other Variables. The remaining aspects of the project are, at least in relative terms, not highly significant determinants, of project performance. The costs of the storage lagoons, pumping and application systems, etc., are large but the impact of changes of these costs over reasonable ranges is not significant. Variations in the discount rate from four to twelve percent did not significantly influence project performance due to the high cost load in the first year of the project.

SELECTED RESULTS AND CONCLUSIONS REGARDING RESEARCH NEEDS

Since the estimates on which this analysis is based are approximate, the results are less than exact. Some of the results will be presented, however, in order to provide a general understanding of the project.

Based on assumptions that appear reasonable for the level of nitrogen present and crop utilization, the following can be reported. Almost 150 dry tons per acre of sludge could be applied in the first ten years, with another 100+tons being applied in the following ten years. The net present value of the cost of the project to the district would be about $68 per dry ton using current transportation methods and about $39 per ton if a pipeline were constructed. The project would generate economic activity in the county amounting to $600 to $1200 per acre depending on the multiplier and assuming that local labor and contractors are used.

It seems that it is reasonable to conclude that a project of this nature is economically feasible. The MSD will be able to dispose of significant quantities of sludge, and if the pipeline is constructed, be able to do so at a lower cost than with previous methods. The county will realize benefits in that significant acreages of strip-mined land will be reclaimed and significant levels of income will be generated. It is this anticipated benefit by both parties that resulted in the initiation of the project[18].

Of course, additional research needs to be done. While the information on which this simulation is constructed is quite crude, the results do suggest areas for further work. The variables identified as important determinants of project performance are the logical candidates for early effort. More information is needed on the nitrogen balance aspects of crop production with sludge and water application. The full range of the production function needs to be determined, along with estimates of possible nitrogen losses to the environment. This information is needed on a variety of crops. While the presumption of no heavy metals pollution is accepted in this analysis, additional work will likely be necessary in this area.

Improved estimates of the costs of site preparation are needed. Perhaps this large-scale project will generate a reasonable set of data on the costs of leveling stripped land under a range of different spoil conditions. Perhaps more efficient techniques of accomplishing the task can also be developed. The wide range of cost data available from small demonstration projects are of minimal usefulness in a project of this type.

In addition to the variables identified here, there are the socio-political aspects of the project that are crucial to its continued operation. Some past experience suggests that these considerations may be more important than the economic-engineering aspects.

While the possibility of problems which would stop this operation exists, it appears that it should be successful. It may well demonstrate that a profitable interaction between agriculture and urban centers is a realistic goal.

ACKNOWLEDGEMENT

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Monitoring Considerations for Municipal Wastewater Effluent and Sludge Application to the Land

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ABSTRACT

Monitoring the performance of the many interrelated systems which are involved in any project employing wastewater or wastewater sludge application to the land can not be looked upon as a substitute for a full understanding of system response prior to project commitment. The role of an on-going monitoring program should be to confirm judgments made at the design stage and where inadequate information is currently available to assure with reasonable certainty the nature of system response adequate safeguards must be provided.

Data is presented representing an overview of current effluent and wastewater sludge quality at Michigan municipal wastewater treatment plants. Additionally model guidelines being used in Michigan for groundwater monitoring associated with on land disposal systems are presented.

Monitoring Objective to Confirm Predictions

The term monitoring denotes the process of observing, checking, keeping track of . . . and as applied to the area of land application of municipal effluent and sludges, from the regulatory agency perspective, it implies confirming the predictions and judgments made at the project development and design stage. Monitoring includes the observation of system performance, checking the quality of affected natural systems, such as the underlying groundwater, and keeping track of environmental impacts as quality changes occur. The results of such monitoring should produce *no surprises!* The information obtained should be fully consistent with the predictions of the project designer as agreed to by the reviewing authority.

Acceptance of this premise establishes more firmly the need for a complete understanding of how the system will respond before commitment is made to a particular design. For example, the hydrogeologic performance of a land irrigation system must be established at the design stage relative to groundwater mounding, direction and rate of lateral movement of the applied wastewater, and anticipated water quality changes at given locations, before the judgment is made that such a system is acceptable. After construction and operation of the facilities, the performance of the system is monitored to *confirm* these judgments. Again we emphasize that there should be no surprises.

Areas of Concern

The use of our land resource for waste renovation or disposal as an alternate to past similar uses of our water and air environment highlight the need for avoidance of the "mistakes" of the past. We are aware of the impact of nutrients in our lakes and streams, of DDT and mercury in our fish. These conditions resulted from past "mistakes", and we must assure that we are looking ahead adequately at potential problems with respect to land use for waste treatment and disposal. The questions of groundwater system contamination, metallic or other toxic residue build-up in soil systems, food chain transfer of such materials to animals or man must be answered. We know that many of these questions are being answered by on-going research and by efforts such as will grow out of this conference. These are questions to be resolved before project commitment rather than as a result of after-the-fact monitoring.

In Michigan some fifty projects are either in operation, under construction or planned which will utilize some form of wastewater effluent application to the land. Additionally, based on 1969 inventory of sludge disposal practices within the state, over 200,000 tons of wastewater sludge are generated each year. This sludge accumulation will greatly increase in the coming years with higher water quality standards and improved wastewater treatment methods. The vast majority of the sludge is incinerated at present, but if effective and economical alternatives are demonstrated changes in utilization or disposal practices will follow.

The quality of this liquid effluent and sludge in terms of its potentially detrimental constituents must be considered early in the development of alternative treatment or utilization proposals. A sampling of sludges and liquid effluent from some 55 communities around the state during 1973 shows a wide range in quality as indicated in appendix Tables 1 and 2. These results represent a single sample survey of existing conditions and should, of course, be viewed as a general representation of variations in quality which may occur in wastewater treatment facilities under current conditions. The impact of constituents such as those measured in the survey on proposed utilization or disposal practices involving land application must be clearly understood. Effects to be observed or monitored after land application practices are employed should be readily predictable.

APPENDIX A

TABLE 1
Wastewater Effluent Assay

	MUNICIPALITY							
TEST PARAMETER	*ADRIAN*	*ALBION*	*ANN ARBOR*	*BAY CITY*	*BATTLE CREEK*	*BENTON HARBOR ST. JOSEPH*	*BRIGHTON*	*CADILLAC*
ph	8.2	7.4	----	----	7.7	7.6	----	7.1
Dis. Hg	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Tot. Hg	<0.2	<0.2	0.3	<0.2	0.2	<0.2	0.7	<0.2
Dis. Cr	<0.01	0.02	0.02	0.12	0.15	0.04	0.01	0.02
Tot. Cr	0.02	0.08	0.02	0.16	0.22	0.12	0.02	0.03
Dis. Cu	0.02	0.02	0.09	0.55	0.02	0.05	0.02	0.01
Tot. Cu	0.02	0.03	0.16	1.2	0.03	0.08	0.06	0.01
Dis. Ni	0.10	0.02	<0.02	0.45	0.40	0.80	<0.02	0.13
Tot. Ni	0.10	0.02	<0.02	0.50	0.40	0.80	<0.02	0.13
Dis. Zn	0.11	0.45	0.05	0.10	0.14	0.50	0.06	0.04
Tot. Zn	0.18	0.78	0.19	0.16	0.17	0.70	0.42	0.05
Dis. Cd	<0.01	<0.005	<0.005	0.01	<0.005	<0.005	<0.005	<0.01
Tot. Cd	<0.01	0.005	0.005	0.01	0.005	0.005	0.005	<0.01
Dis. Pb	0.06	0.02	<0.02	<0.02	<0.02	<0.02	0.07	<0.02
Tot. Pb	0.06	0.02	0.02	0.02	<0.02	<0.02	0.07	<0.02
Dis. Fe	0.08	0.09	0.18	0.08	0.1	0.1	0.21	0.05
Tot. Fe	0.15	1.60	9.2	5.8	0.2	0.4	2.7	0.8
Tot. As	<0.005	0.02	----	----	<0.005	0.005	----	0.007
Tot. Ca	----	59.55	45.58	45.9	80.0	48.63	76.42	30.2
Tot. Mg	----	20.98	12.74	14.8	21.84	17.22	24.69	10.21
Tot. Na	----	110.6	71.1	118.4	77.1	52.3	126.3	51.3
Tot. K	----	5.9	113.0	19.4	7.4	7.6	17.3	12.8
PCB 1242	----	----	----	3.2	----	----	----	----
1254	----	0.34	0.25	----	<0.1	0.20	----	0.53
1242:1254	0.26	----	----	----	----	----	0.33	----
Phthalate	<1.0	5.0	3.0	3.0	1.0	3.0	2.0	15.0

NOTE: All units mg/ l except pH and Hg; Hg expressed as μg/ l; PCB 1242:1254 ratio 1:1

TABLE 1: (Continued)

	MUNICIPALITY							
TEST PARAMETER	*CHARLOTTE*	*CONSTANTINE*	*DETROIT*	*DEXTER*	*EAST LANSING*	*ESCANABA*	*ESSEXVILLE*	*FLINT (ACTIVATED SLUDGE)*
pH	7.7	7.1	7.4	----	7.4	----	----	7.6
Dis. Hg	<0.2	<0.2	<0.2	<0.2	<0.2	----	<0.2	<0.2
Tot. Hg	0.3	0.2	0.5	0.4	<0.2	<0.2	<0.2	0.2
Dis. Cr	<0.01	<0.01	0.01	0.02	0.01	----	0.02	0.01
Tot. Cr	0.01	0.01	0.08	0.03	0.01	0.01	0.02	0.04
Dis. Cu	0.01	0.03	0.14	0.03	0.02	----	0.03	0.06
Tot. Cu	0.14	0.04	0.45	0.07	0.02	0.01	0.04	0.07
Dis. Ni	<0.02	0.02	0.50	<0.02	0.02	----	<0.02	0.14
Tot. Ni	<0.02	0.02	0.80	<0.02	0.02	<0.02	<0.02	0.16
Dis. Zn	0.17	0.03	0.11	0.15	0.06	----	0.04	0.15
Tot. Zn	0.19	0.03	0.80	0.21	0.08	0.22	0.13	0.25
Dis. Cd	<0.01	<0.005	0.01	0.01	<0.01	----	<0.005	<0.005
Tot. Cd	<0.01	<0.005	0.025	0.01	<0.01	<0.005	0.005	<0.005
Dis. Pb	0.03	<0.02	<0.02	0.07	0.05	----	<0.02	0.03
Tot. Pb	0.06	<0.05	0.20	0.07	0.06	0.07	0.20	0.12
Dis. Fe	0.22	0.05	0.10	0.88	0.10	----	0.12	0.05
Tot. Fe	0.62	1.0	21.0	3.8	1.6	0.04	2.2	0.46
Tot. As	0.015	<0.005	0.005	----	<0.005	0.011	----	0.009
Tot. Ca	----	58.22	41.81	79.28	----	54.72	58.22	50.37
Tot. Mg	----	17.29	12.92	31.44	----	13.61	15.05	19.92
Tot. Na	----	177.7	110.4	221.1	----	60.1	138.2	130.3
Tot. K	----	12.8	8.0	26.6	----	13.5	12.0	9.5
PCB 1242	----	----	2.15	----	----	----	----	----
PCB 1254	0.34	0.46	----	0.23	0.18	----	0.1	0.10
PCB 1242:1254	----	----	----	----	----	0.28	----	----
Pnthalate	10	9	14	20	1.0	5.0	<1.0	1.0

NOTE: All units mg/ l except pH and Hg; Hg expressed as μg/ l; PCB 1242:1254 ratio 1:1

The quality of wastewater and sludge observed in this survey argues strongly for industrial waste pretreatment and control. Michigan is committed to the development of such programs within each community and this is also a major objective of the new federal legislation. We must ask, however, will such control measures always be effective? Do we know all of the parameters which should be of concern? Can we routinely accept the premise that the sewage and sewage sludge are of known and predictable quality? As a regulatory agency, we feel strongly that the answers to these questions are a resounding "no". Sewage is variable in nature. Its constituents can and do change with time, with community growth, with industrial development, and with changes in consumer product uses. Any material used by our society may, and in fact probably will, come down the pipe in the form of municipal wastewater. Proposals for waste utilization must give recognition to these uncertainties. Additionally, by its very nature sewage must also be fully respected for its disease transmission potential, both with respect to public contact and with respect to workers associated with the treatment or disposal operation.

System Monitoring Versus Research Needs

A clear distinction should be made between the need for monitoring of performance of individual projects and the vast amount of research and development study now underway or yet to be initiated. The scope of projects involving wastewater application to land in Michigan ranges from the Muskegon County system covering some 10,000 acres and design to treat some 32 million gallons per day, down to systems serving only a few hundred persons in small rural communities. Sludge utilization and disposal systems with on-land application range from small plant loads of only a few hundred pounds per day up to an interim proposal for composting of 200 tons of

TABLE 1: (Continued)

	MUNICIPALITY							
TEST PARAMETER	*FLINT (TRICKLING FILTER)*	*GLADSTONE*	*GRAND HAVEN*	*GRAND RAPIDS*	*HOLLAND*	*HOUGHTON - HANCOCK*	*HOWELL*	*IRON MOUNTAIN - KINGSFORD*
pH	7.4	----	7.6	7.5	7.6	----	7.4	----
Dis. Hg	<0.2	----	<0.2	<0.2	<0.2	----	<0.2	----
Tot. Hg	0.7	0.3	0.7	0.2	0.2	0.3	<0.2	0.3
Dis. Cr	0.02	----	1.0	0.01	<0.01	----	0.02	0
Tot. Cr	0.06	<0.01	1.46	0.46	0.01	0.005	0.34	<0.01
Dis. Cu	0.04	----	0.42	0.11	0.02	----	0.01	----
Tot. Cu	0.05	0.04	0.56	0.28	0.02	0.04	0.01	0.03
Dis. Ni	0.15	----	0.50	0.46	0.06	----	0.02	----
Tot. Ni	0.17	<0.02	0.56	0.78	0.06	<0.02	0.02	<0.02
Dis. Zn	0.1	----	0.44	1.7	0.05	----	0.1	----
Tot. Zn	0.33	0.19	1.6	3.5	0.09	0.12	0.1	0.3
Dis. Cd	<0.005	----	<0.005	<0.005	<0.005	----	<0.01	----
Tot. Cd	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.005
Dis. Pb	0.03	----	0.02	0.02	<0.02	----	0.02	----
Tot. Pb	0.17	<0.02	0.16	0.14	<0.02	0.02	0.05	0.10
Dis. Fe	0.12	----	0.20	0.04	0.08	----	0.18	----
Tot. Fe	0.78	1.5	2.6	5.8	0.14	0.47	0.46	0.55
Tot. As	0.007	0.0063	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Tot. Ca	42.43	72.89	35.94	55.58	56.90	40.24	----	49.38
Tot. Mg	15.49	14.36	13.04	15.05	14.87	7.68	----	21.67
Tot. Na	112.5	48.0	43.4	142.1	61.2	19.2	----	49.3
Tot. K	7.9	11.8	5.8	7.6	7.6	3.9	----	11.0
PCB 1242	----	----	----	----	----	----	----	----
1254	0.16	0.44	<0.1	1.05	<0.1	0.18	----	0.69
1242:1254	----	----	----	----	----	----	----	----
Phthalate	7.0	4.0	11.0	17.0	1.0	<1.0	----	11.0

NOTE: All units mg/l except pH and Hg; Hg expressed as μg/l; PCB 1242:1254 ratio 1:1

sludge per day from the Detroit system, pending completion of additional incinerators. Realism and economics dictate that "research and demonstration" be carried out at the research facilities, academic institutions, or within the scope of the larger projects either in advance of construction or as a controlled portion of such operations, rather than placing the technical cost for such research programs on the smaller systems.

In the case of either large or small systems, where sufficient performance data is not yet available to adequately predict system response, the consequences of poor performance must be anticipated and adequately considered within the design. This may mean the provision of significant isolation zones; the avoidance of approval of systems in areas where possible utilization of affected groundwater systems may occur; or the restriction of methods of application of wastewater or sludge to methods previously demonstrated to minimize undesirable conditions. With regard to systems where sufficient information is not yet available to assure that economic benefits will in fact provide a favorable return from waste *utilization*, the project should be looked upon as a waste *disposal* facility, in economic terms, until the questions are more fully resolved.

Work should be continued in areas such as research into the impact of waste application practices on native wildlife, birds, insects, etc. but such efforts are totally out of place if viewed as a continuing monitoring need at all facilities. If research studies do show adverse impact on such natural systems, or show a potential for disease transmission away from the site, this knowledge should be made readily available to project designers and reviewing authorities along with proposals for modification of past approaches to be undertaken to avoid such detrimental effects. System management should, of course, be targeted in every instance at avoidance of foreseeable problems, such as conditions conducive to creation of

TABLE 1: (Continued)

TEST PARAMETER	MUNICIPALITY							
	IRONWOOD	L ANSE	JACKSON	KALAMAZOO	LANSING	MANISTIQUE	MARQUETTE	MARSHALL
pH	----	----	7.4	7.6	7.4	----	----	----
Dis. Hg	----	----	<0.2	<0.2	<0.2	----	<0.2	----
Tot. Hg	<0.2	0.3	<0.2	<0.2	<0.2	<0.2	0.3	0.5
Dis. Cr	----	----	0.62	0.08	0.03	----	----	0.04
Tot. Cr	<0.01	<0.01	1.0	0.22	0.07	<0.01	0.01	0.04
Dis. Cu	----	----	0.02	0.06	0.21	----	----	0.05
Tot. Cu	0.02	0.02	0.03	0.07	0.28	0.04	0.10	0.08
Dis. Ni	----	----	5.2	0.25	0.25	----	----	0.02
Tot. Ni	<0.02	<0.02	5.4	0.30	0.27	<0.02	<0.02	0.02
Dis. Zn	----	----	0.28	0.33	0.10	----	----	0.05
Tot. Zn	0.11	0.12	0.71	0.30	0.20	0.15	0.65	0.15
Dis. Cd	----	----	0.01	<0.005	<0.01	----	----	<0.005
Tot. Cd	<0.005	<0.005	0.04	0.01	0.01	<0.005	<0.005	<0.005
Dis. Pb	----	----	<0.02	0.02	0.04	----	----	----
Tot. Pb	<0.02	<0.02	0.05	<0.02	0.13	0.02	0.02	0.04
Dis. Fe	----	----	0.05	0.50	0.05	----	----	0.09
Tot. Fe	0.67	0.77	3.2	1.1	0.95	1.4	6.2	0.68
Tot. As	<0.005	<0.005	0.005	0.005	<0.005	0.005	<0.005	<0.005
Tot. Ca	46.43	67.52	88.04	76.02	----	78.69	49.61	55.91
Tot. Mg	9.13	9.27	30.11	25.63	----	16.93	7.16	18.82
Tot. Na	11.5	56.1	64.1	146.1	----	35.8	33.1	67.1
Tot. K	14.5	6.8	9.8	14.1	----	4.8	6.7	5.3
PCB 1242	----	----	----	----	----	----	----	----
1254	----	----	<0.1	----	0.22	0.63	0.29	0.15
1242:1254	----	----	----	----	----	----	----	----
Phthalate	<1.0	<1.0	8.0	3.0	2.0	7.0	24.0	37.0

NOTE: All units mg/ l except pH and Hg; Hg expressed as μg/ l; PCB 1242:1254 ratio 1:1

fly or mosquito populations or the harborage of rats or other rodents.

System Monitoring

Once we have established the fact that monitoring is to be carried out with the purpose of confirming past judgments, what in fact should be monitored? For wastewater systems monitoring should begin with the quality of waste delivered for utilization. Such monitoring takes the dual role of confirming on a day to day basis that the waste being applied is acceptable and also serves as a record over time of the loadings placed on the system. It is presumed at this time that all such wastes will have received a minimum of secondary treatment prior to land application and the parameters to be determined are equivalent to those used to identify wastewater quality for stream discharge. Additionally, parameters needed for confirmation of groundwater quality acceptability and for crop utilization will be necessary. If system operation includes storage prior to application, any changes in quality prior to utilization will also be of interest. An essential element of the management of an application system will be the health and welfare of workers within the site who are subject to wastewater contact during their daily activities, through either body contact or inhalation of wastewater aerosols. In this regard, and as a public health control measure, adequate disinfection prior to application by airborne distribution is essential and the effectiveness of disinfection should be confirmed.

The appendix includes guidelines developed in Michigan for establishment of groundwater monitoring programs at conventional on-land disposal systems of various types. Similar guidelines are being developed for specific application to groundwater monitoring at landfill sites. The groundwater monitoring program outlined is considered to be the minimum acceptable program for systems having no apparent complexities in terms of the tributary waste or

TABLE 1: (Continued)

	MUNICIPALITY							
TEST PARAMETER	*MENOMINEE*	*MIDLAND*	*MILFORD*	*MONROE*	*MOUNT CLEMENS*	*MOUNT PLEASANT*	*MUSKEGON*	*MUSKEGON HEIGHTS*
pH	----	----	7.4	7.5	7.0	----	7.6	7.6
Dis. Hg	----	<0.02	0.3	<0.2	<0.2	<0.2	<0.2	<0.2
Tot. Hg	<0.2	0.2	0.4	<0.2	1.0	0.4	0.8	0.2
Dis. Cr	----	<0.01	<0.01	<0.01	0.01	0.02	0.1	0.04
Tot. Cr	<0.005	0.01	<0.01	0.01	0.02	0.02	1.2	0.11
Dis. Cu	----	0.02	0.02	0.01	0.02	0.05	0.08	0.02
Tot. Cu	0.04	0.03	0.02	0.01	0.02	0.09	0.18	0.02
Dis. Ni	----	<0.02	0.02	0.85	<0.02	0.03	0.14	0.02
Tot. Ni	<0.02	<0.02	0.02	0.95	<0.02	0.03	0.4	0.02
Dis. Zn	----	0.01	0.08	0.10	0.13	0.37	1.0	0.08
Tot. Zn	0.03	0.06	0.09	0.25	0.18	0.42	0.8	0.09
Dis. Cd	----	<0.005	<0.005	<0.01	<0.005	<0.01	<0.02	<0.005
Tot Cd	<0.005	0.005	<0.005	0.01	<0.005	0.01	0.09	<0.01
Dis. Pb	----	<0.02	0.02	0.08	0.05	0.04	0.02	<0.02
Tot. Pb	0.02	0.02	0.02	0.12	1.1	0.06	0.45	<0.02
Dis. Fe	----	0.10	0.02	0.09	0.15	0.16	0.10	0.40
Tot. Fe	1.9	2.0	0.85	0.58	1.0	1.2	2.0	0.40
Tot. As	<0.005	----	<0.005	<0.005	<0.005	----	0.005	0.023
Tot. Ca	83.09	58.55	76.07	----	67.0	----	36.25	34.12
Tot. Mg	20.86	17.16	32.44	----	26.26	----	13.04	13.52
Tot. Na	31.8	89.6	114.5	----	60.2	----	93.8	74.0
Tot. K	8.1	9.3	8.5	----	8.0	----	13.2	13.7
PCB 1242	----	----	----	----	----	----	----	----
PCB 1254	0.57	<0.1	----	<0.1	----	0.29	0.88	0.18
PCB 1242:1254	----	----	2.2	----	2.9	----	----	----
Phthalate	<1.0	5.0	<1.0	<1.0	11.0	12.0	14.0	4.0

NOTE: All units mg/ l except pH and Hg; Hg expressed as μg/ l; PCB 1242:1254 ratio 1:1

the disposal site. Unique conditions at the facility could dictate expansion of the monitoring program. An effort has been made in the development of this type of monitoring program to minimize the technical expertise necessary and cost involved in providing an effective program. This is accomplished by use of indicator parameters, similar to the indicator organisms used in water and wastewater bacterial testing, as a means of noting deviations of groundwater quality.

For sludge applications to the land, the quantity and quality of material to be utilized or disposed of is of significance, but the initial question as to acceptability of a given quality material for a given use must be resolved before commitment to the program is made. These answers come from a research, not system monitoring. Questions regarding the short and long range impact of a given constituent on land utility, on crop production, and on crop utilization should be resolved before commitment of a significant land resource. Interim utilization of areas of *disposal* may be necessary while some of these answers are being derived.

Once acceptable limitations are known with regard to acceptable wastewater or sludge quality, system loading rates, the significance of airborne bacterial or viral movement, plant uptake of metals or toxic constituents and the range of other research needs being discussed within this conference, and a system developed to operate within these limitations, then monitoring of loadings, response, and performance can be readily employed.

Every effort should be made to simplify such monitoring programs and we feel that this in fact can be accomplished. The success or failure of a project can not rest upon the results of monitoring. The community, the state and the federal government have spent their money for a reliable system and the results of a monitoring program is not the time to find out that it isn't going to work.

TABLE 1: (Continued)

	MUNICIPALITY							
TEST PARAMETER	NILES	NORWAY	OWOSSO	PONTIAC (AUBURN RD)	PONTIAC (EAST BLVD.)	PORT HURON	SAGINAW	SAULT STE. MARIE
pH	7.4	----	7.2	7.5	7.5	6.6	----	----
Dis. Hg	<0.2	----	<0.2	<0.2	<0.2	<0.2	<0.2	----
Tot. Hg	0.2	<0.2	0.3	<0.2	0.5	0.3	<0.2	0.2
Dis. Cr	<0.01	----	0.01	0.03	0.03	0.23	0.06	----
Tot. Cr	0.17	0.01	0.15	0.04	0.05	0.35	0.12	<0.01
Dis. Cu	0.5	----	0.03	0.02	0.04	0.38	0.05	----
Tot. Cu	1.3	0.04	0.04	0.03	0.05	1.0	0.08	0.05
Dis. Ni	0.3	----	0.02	0.13	0.18	0.02	0.05	----
Tot. Ni	0.34	<0.02	0.02	0.18	0.18	0.02	0.05	<0.02
Dis. Zn	0.58	----	0.11	0.06	0.09	0.40	0.03	----
Tot. Zn	1.2	0.14	0.50	0.17	0.15	4.7	0.35	0.16
Dis. Cd	<0.005	----	<0.005	<0.01	<0.01	<0.005	0.01	----
Tot. Cd	<0.005	<0.005	0.15	<0.01	<0.01	<0.005	0.03	<0.005
Dis. Pb	0.07	----	0.03	0.02	0.02	0.02	<0.02	----
Tot. Pb	1.3	0.02	0.28	<0.02	<0.02	<0.02	0.10	0.07
Dis. Fe	0.14	----	0.12	0.09	0.16	0.08	0.08	----
Tot. Fe	5.0	0.25	0.78	0.65	0.83	1.10	3.50	1.6
Tot. As	0.009	<0.005	<0.005	----	0.007	<0.005	----	<0.005
Tot. Ca	56.57	70.54	48.13	71.14	75.36	102.14	56.9	65.18
Tot. Mg	27.15	31.82	16.70	16.70	17.22	32.17	14.68	16.93
Tot. Na	122.4	41.2	130.3	108.3	98.0	61.2	157.9	52
Tot. K	5.5	11.0	7.9	6.3	5.9	6.6	7.3	5.9
PCB 1242	----	----	----	----	----	----	----	----
1254	0.48	<0.1	0.12	----	----	----	----	0.73
1242:1254	----	----	----	0.60	0.54	1.8	0.77	----
Phthalate	4.0	3.0	6.0	3.0	5.0	8.0	8.0	2.0

NOTE: All units mg/ 1 except pH and Hg; Hg expressed as μg/ 1; PCB 1242:1254 ratio 1:1

TABLE 1: (Continued)

	MUNICIPALITY							
TEST PARAMETER	*ST. IGNACE*	*THREE RIVERS*	*TRAVERSE CITY*	*TRENTON*	*WARREN*	*WAYNE COUNTY*	*WYOMING*	*YPSILANTI*
pH	----	7.5	6.6	7.8	8.2	9.3	7.3	----
Dis. Hg	----	<0.2	<0.2	<0.2	<0.2	0.2	<0.2	<0.02
Tot. Hg	<0.02	<0.2	0.2	0.2	<0.2	0.2	0.4	<0.02
Dis. Cr	----	<0.01	<0.01	0.01	0.03	0.03	0.15	0.01
Tot. Cr	<0.01	0.01	<0.01	0.02	0.10	0.55	0.64	0.17
Dis. Cu	----	0.02	0.02	0.04	0.01	0.08	0.15	0.08
Tot. Cu	0.04	0.02	0.02	0.10	0.05	0.18	0.30	0.10
Dis. Ni	----	<0.02	<0.02	0.04	0.4	0.04	0.86	0.42
Tot. Ni	<0.02	<0.02	<0.02	0.05	0.4	0.04	1.3	0.47
Dis. Zn	----	0.21	0.09	0.06	0.12	0.27	0.10	0.25
Tot. Zn	0.19	0.15	0.10	0.18	0.27	0.85	0.37	0.70
Dis. Cd	----	<0.005	<0.005	<0.005	<0.005	0.04	<0.005	0.02
Tot. Cd	<0.005	<0.005	<0.005	0.01	0.025	0.09	<0.005	0.03
Dis. Pb	----	0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02
Tot. Pb	0.05	0.06	<0.02	0.10	<0.02	0.12	0.06	0.05
Dis. Fe	----	0.08	0.05	0.10	0.10	0.2	0.06	0.05
Tot. Fe	0.40	0.16	0.70	2.4	0.60	13.0	1.2	0.62
Tot. As	<0.005	0.005	<0.0045	<0.005	QNS	0.007	0.005	----
Tot. Ca	187.45	49.73	42.75	95.19	52.64	55.91	28.71	57.89
Tot. Mg	9.13	18.49	11.75	15.93	13.70	18.82	6.61	23.85
Tot. Na	43.9	67.1	43.4	122.4	----	142.1	44.4	110.4
Tot. K	5.7	62	8.3	19.9	----	9.7	7.7	66.2
PCB 1242	----	----	----	----	----	----	----	----
PCB 1254	0.31	<0.1	<0.1	<0.1	<0.1	0.40	0.22	0.31
PCB 1242:1254	----	----	----	----	----	----	----	----
Phthalate	<1.0	1.0	<1.0	<1.0	1.0	12.0	4.0	2.0

NOTE: All units mg/ L except pH and Hg; Hg expressed as μg/ l; PCB 1242:1254 ratio 1:1
QNS - Quantity Not Sufficient

TABLE 1: (Continued)

TEST PARAMETER	*MUNICIPALITY* *Ypsilanti Twp #1*	 *Ypsilanti Twp #2*
pH	----	----
Dis. Hg	<0.2	<0.2
Tot. Hg	<0.2	<0.2
Dis. Cr	0.04	0.01
Tot. Cr	0.10	0.30
Dis. Cu	0.02	0.01
Tot. Cu	0.02	0.01
Dis. Ni	<0.02	<0.02
Tot. Ni	<0.02	<0.02
Dis. Zn	0.09	0.06
Tot. Zn	0.14	0.13
Dis. Cd	<0.005	<0.005
Tot. Cd	<0.005	<0.005
Dis. Pb	<0.02	<0.02
Tot. Pb	<0.02	<0.02
Dis. Fe	0.10	0.05
Tot. Fe	0.40	0.06
Tot. As	----	---
Tot. Ca	35.03	35.94
Tot. Mg	10.55	11.86
Tot. Na	81.2	77.1
Tot. K	9.2	9.1
PCB 1242	----	----
PCB 1254	<0.1	<0.1
PCB 1242:1254	----	----
Phthalate	<1.0	<1.0

NOTE: All units mg/ l except pH and Hg; Hg expressed as µg/ l; PCB 1242:1254 ratio 1:1

APPENDIX B

TABLE 2
Wastewater Sludge Assay

	MUNICIPALITY							
Test Parameter	*Adrian*	*Albion*	*Ann Arbor*	*Bay City*	*Battle Creek*	*Benton Harbor - St. Joseph*	*Brighton*	*Cadillac*
STAGE	C	C	E	E	E	B	C	C
% Solids	5.6	32.0	56	68	26	3.7	.08	4.0
Hg	2.0	2.7	3.7	.60	1.0	7.0		4.2
Cr	3800	500	106	1840	2400	4600		600
Cu	2600	260	310	1260	700	1360		700
Ni	1440	14	30	1240	460	1500		280
Fe	14000	11000	40000	25000	22000	22000	QNS	23000
Zn	4800	3200	480	1420	1640	12800		1380
Cd	260	48	4	80	8	220		36
Pb	520	240	86	140	320	540		500
As	6.0	6.0	7.0	6.5	6.8	11.0		5.9

Note: All units mg/kg (air dry basis)
Except % Solids

Stage
A. Undigested liquid sludge
B. Primary digestor sludge
C. Secondary digestor sludge
D. Aerobic digestor sludge
E. Vacuum filter cake
F. Centrifuge cake
G. Drying bed cake
H. Ash classification

QNS - Quantity Not Sufficient

	MUNICIPALITY							
Test Parameter	*Charlotte*	*Constantine*	*Detroit*	*Dexter*	*East Lansing*	*Escanaba*	*Essexville*	*Flint*
STAGE	-	G	E	C	E	C	B	A
% Solids	13	27	31	13	21	7.7	30	6.9
Hg	4.3	3.0	1.2	16	0.9	3	1.4	2.6
Cr	52	88	3200	172	200	680	7200	1080
Cu	1600	300	1060	540	480	740	290	540
Ni	50	20	1420	48	24	20	110	650
Fe	14000	17200	50000	22000	60000	1280	20000	14200
Zn	1800	1600	3100	1480	860	2600	5200	4000
Cd	14	16	92	36	6	10	4	20
Pb	340	400	880	340	200	1100	174	26000
As	7	4	8.5	16	7	9.4	6.5	3

TABLE 2: (Continued)

Test Parameter	*Gladstone*	*Grand Haven*	*Grand Rapids*	*Holland*	*Holland*	*Houghton-Hancock*	*Howell*	*Iron Mountain-Kingsford*
Stage			E	F	H	D		C
% Solids	25	16	29	44	59	2.2	6.4	8.5
Hg	11	6.5	3.2	2.6	> .1	9	3.0	6.6
Cr	28	1380	10600	90	120	76	30000	72
Cu	420	920	2600	206	300	960	900	360
Ni	20	200	2800	<20	<20	40	240	20
Fe	6800	4400	60000	9200	60000	12200	14200	13000
Zn	1080	3200	9400	1860	9000	760	5200	1520
Cd	4	14	480	10	12	4	18	6
Pb	240	600	3000	240	240	740	3000	800
As	3.8	4.0	9.0	5.	6.	1.6	10	7.5

Test Parameter	*Ironwood*	*L'Anse*	*Jackson*	*Kalamazoo*	*Lansing*	*Manistique*	*Marquette*	*Marshall*
STAGE	E	G	C	E		C	C	C
% Solids	46	9.0	6.7	40	33	21	18	8.7
Hg	2.2	7.0	1.9	2.4	2.0	3.4	6.4	56
Cr	28	52	9600	1260	940	22	80	1040
Cu	580	700	720	700	1900	580	520	1060
Ni	20	20	1200	520	1060	620	20	100
Fe	36000	13000	26000	4400	36000	11400	9000	16000
Zn	840	156	6800	1760	3200	1200	1240	2800
Cd	4	8	520	12	40	4	2	16
Pb	340	280	560	340	900	400	360	320
As	2.8	3.4	17	5.5	10	5.9	8.1	12

Test Parameter	*Menominee*	*Midland*	*Milford*	*Monroe*	*Mt. Clemens*	*Mt. Pleasant*	*Muskegon*	*Muskegon Heights*
STAGE	C	E	E		C	C	C	C
% Solids	19	56	36	19	14	11	13	4.2
Hg	3.0	5.4	1.2	.4	5.2	7.5	9.4	20
Cr	220	60	66	60	64	62	4600	800
Cu	460	400	460	140	500	840	940	1240
Ni	<20	12	14	40	<20	40	1040	220
Fe	16400	9600	62000	18000	18000	15600	17600	14800
Zn	1800	660	660	2600	2000	2200	16400	3000
Cd	4	10	2	8	12	14	166	150
Pb	520	300	80	180	2400	400	1860	680
As	8.1	10	11.	5	8	8	8.0	7.0

TABLE 2: (Continued)

Test Parameter	MUNICIPALITY							
	Niles	*Norway*	*Owosso*	*Pontiac (Auburn Rd)*	*Pontiac (E. Blvd)*	*Port Huron*	*Saginaw*	*Sault Ste. Marie*
STAGE	C	C	C	E	C	G	E	B
% Solids	7.1	1.7	10	21	8.4	49	70	16
Hg	3.0	3.0	10	2.0	2.0	3.0	27	3.2
Cr	1920	340	2100	360	360	440	124	44
Cu	10400	700	600	680	940	4800	84	600
Ni	480	20	100	260	420	20	52	20
Fe	44000	13400	18000	24000	20000	3200	14000	9000
Zn	6800	1120	5400	2800	2800	11000	740	72
Cd	14	2	1100	8	12	8	48	2
Pb	12400	900	1560	420	620	720	154	480
As	18	5.6	4	10	11	7.0	10	4.1

Test Parameter	MUNICIPALITY							
	St. Ignace	*Three Rivers*	*Traverse City*	*Trenton*	*Warren*	*Wayne County*	*Wyoming*	*Ypsilanti*
STAGE	C	G	C	A	A	E	E	A
% Solids	14	14	5.4	3.4	4.3	23	25	6.6
Hg	8.2	3.5	8.5	1.5	3.4	3.4	0.72	1.4
Cr	28	900	52	380	3100	2500	5600	1800
Cu	820	500	1100	200	1740	820	2400	340
Ni	20	20	<20	108	740	66	2400	640
Fe	11000	10000	28000	40000	21000	36000	19200	13200
Zn	1120	4600	1560	1460	3800	3500	2200	8400
Cd	4	44	10	8	110	280	14	166
Pb	1280	3600	420	150	400	500	480	2300
As	7.2	1.8	10	9.0	9.0	8.0	8.	10

Test Parameter	MUNICIPALITY	
	Ypsilanti Twp. #1	*Ypsilanti Twp. #2*
STAGE	A	A
% Solids	5.3	4.6
Hg	1.2	2.1
Cr	7800	66
Cu	360	240
Ni	90	44
Fe	44000	144000
Zn	5000	900
Cd	6	6
Pb	1400	300
As	7.5	16

APPENDIX C

Groundwater Monitoring Guidelines on Land Waste Disposal Facilities

Monitoring Objectives

The function of a groundwater monitoring program for proposed land disposal facilities is to confirm judgments made during design. This is to be accomplished by a continuing long-term in-depth hydrogeologic study regarding the performance of the system and its influence on surrounding groundwater conditions. This applies to:

1. Wastewater treatment lagoons
2. Wastewater storage lagoons
3. Land irrigation systems
4. Large subsurface disposal fields
5. Wastewater sludge disposal sites
6. Industrial waste concentrates disposal sites

At all such existing sites groundwater monitoring programs are needed to determine the influence of disposal practices on the groundwater resource.

Design of Monitoring Wells

Monitoring wells must be designed and located to meet the specific geologic and hydrologic conditions at each site. Consideration must be given to the following:

1. Geological soil and rock formations existing at the specific site.
2. Depth to an impervious layer.
3. Direction of flow of groundwater and anticipated rate of movement.
4. Depth to seasonal high water table and an indication of seasonal variations in groundwater depth and direction of movement.
5. Nature, extent, and consequences of mounding of groundwater which can be anticipated to occur above the naturally occurring water table.
6. Location of nearby streams and swamps.
7. Potable and nonpotable water supply wells.
8. Other data as appropriate to the specific system design.

Groundwater quality should be monitored immediately below the water table surface near the application site as pollutional materials entering the groundwater system may have a tendency to remain in the upper few feet. Applied wastewater will generally be depressed within the groundwater system as the material travels away from the site. The need for sampling at more than one depth within a groundwater system will depend upon geologic conditions and distance from the pollutional source and definition of the flow system with depth will be necessary to properly determine the depth to be monitored, especially when mounding is superimposed on the existing system.

Additional design and construction considerations are:

1. Monitoring wells in fine textured soils will require special construction such as gravel packing around the screen.
2. Wells constructed to a depth of 20′ or more should be 4′′ in diameter to facilitate use of submersible pump equipment for sample collection unless alternative sampling methods are approved by the reviewing agency.
3. Construction should be by a registered well driller or contractor covered under Act 315, PA of 1969 using approved modern construction methods.
4. Casings shall be grouted and capped and a cap-locking device provided. Use of a vented cap is desirable but care must be taken to prevent introduction of contaminants thru such vents.
5. The well casing should be protected against accidental damage and adequately marked to be clearly visible during winter and summer conditions.
6. Each well should be labeled and identified (owner, owners address, well number, use of well and warning).
7. If a monitoring well is to be permanently abandoned, approved procedures are to be followed.

Location

Groundwater monitoring wells must be located so as to detect any influence of wastewater application on the groundwater resource. A minimum of one groundwater monitoring well must be provided in each direction of groundwater movement near the pollutional source with adequate consideration being given to possible changes in groundwater flow due to mounding effects. The orientation and spacing of multiple wells shall be determined by conditions at each site.

Water Level Measurement

The following considerations apply with regard to water level measurement:

1. Water levels should be determined by methods giving precision to 1/8 inch or 0.01 feet. (Example—wetted tape method)
2. Measurements should be made from the top of the casing with the elevation of all casings in the monitoring wells system related to a permanent reference point, using USGS datum.
3. Water level measurements are to be made under static conditions prior to pumping for sample collection.

4. Monitoring wells should be installed early in the construction sequence and monthly water level readings obtained during the construction period and during the first two years of wastewater system operation to provide background information. Subsequent water level measurement frequency should be in accordance with a schedule established on a case by case basis.
5. All wells should be securely capped and locked when not in use.

Water Sampling

Background water quality. A minimum of three monthly samples should be collected from each monitoring well prior to placing the storage or disposal facility in operation. In cases where background water quality adjacent to the site may be influenced by prior waste applications, provision of monitoring wells or analysis of water quality from existing wells in the same aquifer beyond the area of influence will be necessary.

Operating Schedule. Samples should be collected monthly during the first two years of operation. After the accumulation of a minimum of two years of groundwater monitoring information, modification of the frequency of sampling may be considered upon written request.

Sample Collection

1. A measured amount of water equal to our greater than three times the amount of water in the well and/or gravel pack should be exhausted from the well before taking a sample for analysis. In the case of very low permeability soils the well may have to be exhausted and allowed to refill before a sample is collected.
2. Pumping equipment shall be thoroughly rinsed before use in each monitoring well.
3. A pressure tank shall not be used with a sampling system since the water in the pressure tank would be particularly difficult to exhaust.
4. Water pumped from each monitoring well should be discharged to the ground surface away from the wells to avoid recycling of flow in high permeability soil areas or soil erosion.
5. Samples must be collected, stored, and transported to the laboratory in a manner so as to avoid contamination or interference with subsequent analyses.

Sample Analysis

Water samples collected for background water quality should be analyzed for the following: (Note: Parameters for groundwater monitoring at industrial waste disposal sites must be established on an individual basis depending on the composition of the wastes applied).

1. Chloride
2. Specific Conductance
3. pH
4. Total hardness
5. Alkalinity
6. (a) Ammonia nitrogen
   (b) Nitrate nitrogen
   (c) Nitrite nitrogen
7. Total phosphorus
8. Methylene blue active substances
9. Chemical oxygen demand*
10. Any heavy metals or toxic substances found in the applied wastes.

After adequate background water quality information has been obtained, a minimum of one sample per year, obtained at the end of the irrigation season in the case of seasonal operations, should be collected from each well and analyzed for the above constituents.

All other water samples collected in accordance with the operating schedule should be analyzed for chlorides and specific conductance as indicators of changes in groundwater quality resulting from the wastes applied. If significant changes are noted in chloride and/or specific conductance levels, samples should immediately be analyzed for the other parameters listed above to determine the extent of water quality deviation from background levels.

Groundwater Monitoring System Reports

Well location plan. The owner of the system is to provide a plan, drawn to scale, showing the location of each monitoring well and its relationship to the wastewater treatment lagoons, storage lagoon, irrigation area, sludge disposal site or subsurface disposal field and to other significant features such as municipal or private wells, surface streams, etc. It is suggested that individualized well location plan maps be prepared by the project consultant. The plan map shall include casing elevation information to facilitate conversion of water level measurements to datum elevations.

Reports. The owner of the system is to file standard reports of observations and sample analyses, obtained in accordance with the schedule listed above, with the responsible state agency within 30 days of sample collection. Notification of significant deviations from background quality is to be given immediately.

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* Use of low concentration C.O.D. analysis methods per current edition of *Standard Methods* may be necessary.

DISCUSSION

QUESTION: Robert Dean, EPA. Are you going to apply different standards to spreading of effluent on the land than you apply to the workers who have to work in the conventional sewerage treatment plants today, with regard to spray and things like that.

ANSWER: I think that as we get into these kinds of questions, we have to deal with all of the alternatives and I think there are some serious questions that have to be addressed and have to be answered. We talked about the various alternatives for different disposal methods, stack emissions from incineration should be zeroed in on and given the same kind of emphasis that we are giving these considerations here. It is simply a matter as I see it right now of too many questions to be asked to get answers to all at once. We are using this forum right here to answer some of the questions. There are a lot more to be answered.

QUESTION: Robert Schneider, Office of Water Resources Research. First, is monitoring a legal regulatory requirement in Michigan? I am thinking in particular of the effluent in ground water or in streams. Second, you mentioned that the chemical quality of sludges varies considerably and also that the purpose of the monitoring or the general objective is that monitoring should result in no surprises. Now, how could you differentiate between changes in quality resulting from surprises and those changes that result in changes of quality of the sludge?

ANSWER: Let me see if I can get them in order. Let me deal with the changes and the surprises thing. We are trying to emphasize that there has to be a very detailed look at the project as a whole before we get into commitment to it.

Per se there is no statute that says thou shall monitor ground water given projects. It is an administrative type action that we, as the state regulatory agency, are implementing. We recognize that we are deficient, we are slow in getting this kind of a program underway in that we have had lagoon systems in the state for 10 and 15 years that have never filled up. It never went out to the stream the way it may have been designed. So now we are going back and taking a look at the ground water systems and this is going to be a significant task to go back to these communities, knock on the door and say hey, we missed something, let's check and see whether or not we got some detrimental impact here in the ground water. We are looking at monitoring on any new project as an intrical part of the development of project and some projects are going to be far more complex than others and some systems a type surveillance and so on. We may be able to dismiss it quite quickly.

QUESTION: By George Ward, Portland, Oregon. Darwin, I would like to ask you one. Could you give us generally the Washington EPA's opinion on financing of sludge incinerators, if there is one, and then also is there anyone in the audience or speakers left that cares to talk about known or suspected hazards of sludge incineration.

ANSWER: Darwin Wright, EPA. We did have a task force on incineration and we have completed a report. We recognized that there are some air pollution problems with incinerators, but I know that there are some groups that are going ahead, Blue Plains is building some rather large incinerators.

ANSWER: John Trax, EPA. I think one of the critical problems identified in this task force was the PCB's, and what happens to them when they are incinerated. We don't know very much about this. We realize that there is a lot of work to be done in terms of determining the health effects as related to incineration of sludge and refuse or a joint incineration of sludge and refuse. We don't have any projects initiated to look at these problems. Maybe Bob Dean has something to add to this.

ANSWER: Bob Dean, EPA. On the incinerator approach, I have taken the attitude for ultimate disposal that incineration is one of the acceptable ways of disposing of wastes or at least reducing the organic content and I have also found that it is very often not the most cost effective method. If you put on all the necessary controls. Now, incinerators can be operated to meet extremely strict controls and they are so operated in the State of California, in the San Francisco Bay region. Now, Los Angeles region has taken the attitude that they don't think an incinerator could ever meet the code that they will get around to writing, but this is sort of discouraging to anybody who wants to build an incinerator. However, incinerators can meet the codes. The PCB problem arose from the fact that we couldn't find PCB after the sludge had been incinerated and we knew it was there and we didn't see how it could have gotten away because when pure PCB's are incinerated under those same conditions, they surely would have gotten out. But there has been some more recent work not yet substantiated but we are working on it, that shows as long as there is something else burning at the same time, the PCB's aren't all that hard to get rid of.

I have another rather interesting fact. The task force that John is referring to, mentioned levels of PCB's including one city where they made them, of over 105 parts. I would like to get this in the record. Against a national background of around three. That corresponds to the geometric mean. Eighteen months later it is down closer to 20 than it is to 100 after the voluntary phasing out of PCB's in business forms. Furthermore, two local plants in Cincinnati that have been up in the 20 to 30 range, probably because they were re-pulping a lot of paper to make packing cartons, are now down in the three to five range, about where you would expect the rest of the country to be. So, it looks like the voluntary controls on PCB's are being effective in most areas. We still find a few places that have high PCB and we want to trace one down, maybe somebody is salvaging copper from old transformers, you know you are allowed to use PCB's in transformers, but you are suppose to be careful how you scrap them, and they do burn up every once in awhile too. So, maybe the PCB's aren't so bad.

I think my message is you can use incineration but you have got rather expensive controls and quite a lot of energy used and that cost has to be recalculated as the cost of energy starts to go up.

Institutional Options for Recycling Urban Sludges and Effluents On Land

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ABSTRACT

Analysis of institutional options for recycling effluents and sludges from urban wastewater treatment plants on land indicates the presence of numerous alternative methods for financing, operating, and organizing large scale programs. The effects of technical, social, political and legal constraints are examined and found to be significant in the determination of preferred alternatives.

The experiences of the Metropolitan Sanitary District of Greater Chicago (MSDGC) are extensively used to illustrate available institutional options. The MSDGC has been active in land application of sludge and is currently engaged in a very large scale project to apply sludge to rural, stripmined land approximately 200 miles from the center of its collection and treatment activities.

Preferred methods of financing are bond sales or State and Federal grants for capital improvements, and current taxation for normal maintenance and operation activities. The preferred alternate for operation of land application facilities is believed to require the purchase of large rural tracts. Land development must be achieved through careful planning activities conducted with close cooperation between local government agencies of the rural receiving area and the urban producing area. There exists an urgent need for State and Federal conceptual commitment, and financial and technical assistance to land application programs.

INTRODUCTION

The problems associated with land application of urban sludges and effluents have been well documented in technical journals as well as in the popular media. Numerous articles outline the dimensions of the problem, characterize various sludges and effluents, and describe the land selected to dispose of those materials. The literature dealing with land application contains a significant information relative to the plants to be cultivated in such agricultural operations, and documents the relationships between those plants and the components of the sludges and effluents used to nourish them. Not so well documented, however, are certain practical problems dealing with the options available to an agency or institution for implementing a large scale land application program. As with any program, operational, financial, political and social alternatives are available.

The Metropolitan Sanitary District of Greater Chicago (MSDGC) has been active in the area of land application of digested sewage sludges since the mid-1960's. It is the purpose of this paper to draw heavily from the experiences of the MSDGC in order to describe and discuss some of the alternatives available to an organization undertaking a program of application of sludges and effluents to the land.

Financial Alternatives

The financial alternatives available for any large-scale program of land application are, in general, the same as those normally available to the sludge-effluent producing agency to satisfy its other long-term and short-term economic resource requirements. Alternative means of financing are:

a. Sale of bonds
b. Current taxation
c. State and Federal Grants
d. Sale of sludges and effluents

The MSDGC has used bond sales, current taxation and State and Federal grants to finance portions of its land application programs. The MSDGC has not, as yet, been successful in selling liquid sludges to generate income. The alternative of financing the land application of sludge or effluents by their direct sale to farmers or other buyers must probably be discounted at this time due to the fact that use of these materials has not been perceived by individual farmers as being economically desirable. Much technical and promotional development will be required before liquid sludges and effluents can be successfully marketed. However, the basic capability of sludges and effluents to provide necessary nutrition and irrigation to agricultural lands may in time overcome current attitudes and beliefs which, in part, preclude commercial sales at this time. It is entirely possible that in future years sludges and effluents will be in demand by agricultural interests and that this new market will provide at least a part of the revenue required to deliver and apply the materials to the land.

Financial alternatives may be used either to the exclusion of each other or to supplement each other. In general, bonds are sold to obtain funds to pay for large new capital improvements and current taxation is used to pay for relatively constant, recurring costs associated with normal maintenance and operation. It would appear that land application programs do not possess any characteristics which would cause the selection of financial options to be made in a manner different from that normally used in any construction and operation program. If land for the application program is purchased, funds would be available from the sale of bonds. However, if land is leased, the necessary funds may have to be generated from current revenue. Improvements to the land such as grading, construction of berms, dikes, reservoirs, holding basins, and monitoring wells will almost invariably be paid for by funds generated by the sale of bonds. Likewise, pipelines, pumps, aeration units and other process equipment required both in the application fields and in the plant, which is the source of the sludges and effluents, will be purchased and installed with bond generated funds.

Various methods of transporting sludges and effluents from their source to the application site must be considered. It is very difficult, if not impossible, to find suitable land in close proximity to large urban centers. Therefore, the cost of transportation is likely to be a large factor in the total cost of a land application program. If transportation is provided by awarding a contract to a private enterprise, the cost of this service may be paid in a series of payments based on quantities shipped. Such payments may be made from proceeds of current taxation. However, if transportation is provided by the producing agency itself by purchasing trucks, rail cars, barges, or a pipeline, the cost of such capital equipment will probably best be paid for by proceeds from bond sales. The operating costs for the transport equipment, like the operating costs of other system components, would almost certainly be paid from proceeds from current taxation.

A suitable alternative to bond generated funds are State and Federal Grants. Such funds are frequently, although not always nor dependably, available and are allocated according to such factors are current appropriations, and State and regional priorities.

By way of example, the MSDGC is currently developing strip-mined land in Fulton County, Illinois, approximately 200 miles from the center of its collection and treatment facilities in Chicago. The MSDGC considered various alternative transportation systems, particularly rail and barge, for its initial operation. Barge shipment was finally selected because of its greater economy over the time period considered. Finally, the MSDGC elected to contract for the barge hauling. The details of the contract are rather complex, but basically the agreement provides for periodic payments to be made to the contractor on the basis of sludge volume shipped. Payments are made from the revenues obtained from current taxation. However, the MSDGC has chosen to pay for the capital improvements required for the land application program from the proceeds of bond sales. In addition, the MSDGC applies for Federal and State grants for all capital expenditures required for its land application program. Such grants have been a significant factor in overall financing.

Operational Alternatives

A number of operational alternatives for land application programs are available to the producing agency. A partial list of alternatives follows:

a. Purchase land, develop and operate.
b. Purchase land, contract development and operation.

c. Purchase land, develop and contract operation.
d. Contract land acquisition, development and operation.
e. Lease land, develop and operate.
f. Lease land, contract development and operation.
g. Lease land, develop and contract operation.
h. Deliver application material to private landowners.

In principle, any one of the above alternatives may be used simply or in combination with each other to fulfill the basic requirement of delivering and applying sludges and effluents to the land. However, there are a variety of social, political, financial and technical constraints that, in fact, severaly limit one's freedom of action. Some of the experiences the MSDGC has encountered in implementing its solids-on-land program are quite useful in illuminating the various constraints which apply to some of the alternative techniques. The degree to which certain constraints apply to some alternatives, but not to others, is a major factor in determining preferred options.

In the early stages of its land application program, the MSDGC searched for relatively large plots of nonproductive soils within its jurisdictional boundaries. Very early in the program, conducted within the borders of the MSDGC, negative public opinion was encountered. For this reason, the program was aborted early in its development.

Most of the MSDGC's service area is urbanized. Even "farm" areas within the borders of the MSDGC have high population densities when compared to rural farms. Furthermore, "farm" areas which currently exist within the MSDGC are rapidly undergoing a contraction as virtually unrestrained suburban growth causes acreage to be taken out of agricultural production. The growth of the suburbs acts in two negative ways to undermine the potential success of a land application program. First, and most obvious, the suburbs bring a large influx of people of non-farm background into a previously agricultural area. The lack of familiarity of the new suburbanites with agricultural operations, and their attitudinal inclination to regard sludges and effluents as undesirable wastes, make it practically impossible to conduct a large scale land application program in such areas. The second way in which the growth of the suburbs acts to impede the success of land application programs is by its effect on land values. The economic viability of a land application program rests heavily on the availability of relatively inexpensive terrain. Land prices which prevail in the major agricultural producing areas of Illinois and other midwestern states are currently low enough to permit land application in an economically acceptable manner. However, land prices in most suburban areas and central cities are such that they render land application economically unjustifiable. If an outlet from urbanized areas cannot be found, other alternatives, usually consisting of processing plants and facilities, must be considered. Within the highly specialized environment of large urbanized areas, complex and costly mechanical and chemical treatment facilities must be constructed because of economic considerations even though it is known that such techniques are not as favorable to the natural ecology of the environment as recycling processes such as land application. The conclusion to be drawn from the foregoing is that it is of paramount importance to a land application program that the urban producing agency have access to large acreages in rural area.

The MSDGC soon came to appreciate the need for access to rural areas. As the MSDGC has no powers of eminent domain outside its borders, it realized that it would have to offer general benefits to rural receiving areas in addition to simple monetary compensation to individual land owners in return for their properties. Accordingly, the MSDGC methodically began to search for unproductive lands, within a 250 mile radius of Chicago, which could benefit from the application of sludge. Such lands could be made productive, increasing the wealth of the local community, while simultaneously providing a needed outlet for sludges generated in the urban area. It is interesting to view sludges and effluents in the context of economic resources which are supplied and demanded. The enormous imbalance between supply and demand in urban areas prevents the formation of a market in which sludges and effluents can be supplied at a positive price. Hence, in urban areas, sludges and effluents are supplied to "buyers" at a negative price, i.e., suppliers must pay to have the materials removed from their premises. It is in this context that sludges and effluents are considered to be wastes. However, if sludges and effluents can be transported to rural regions, it is at least possible that supply and demand curves could intersect at a positive value. Of course, substantial effort is required to stimulate demand even in rural areas, but it is at least conceivable that sludges and effluents could become marketable commodities in certain regions in coming years.

In late 1970, the MSDGC located strip-mined lands in Fulton County, Illinois, about 200 miles from Chicago, which at that time were marginally productive in an agricultural sense. Working in close cooperation with the Fulton County Board of Supervisors, the MSDGC developed its "Prairie Plan", a comprehensive and detailed program whose salient character was the emphasis on *mutual* benefit to both the receiving area and the donor area. The experiences of the MSDGC in implementing a large scale land application plan in Fulton County are significant, in that they illustrate many of the problems that influence a land acquisition program. The MSDGC would have preferred acquiring cropland instead of strip-mined land, due to the relatively high costs of rehabilitating the latter. Strip-mined land is highly irregular, often covered with spoil-banks, and has to be leveled before use. In general, land application programs require a closed system to prevent field run-off from entering streams before sampling can be completed to assure that water flowing into waterways meets applicable standards. The design and construction costs of such closed systems are quite high, generally greater than the purchase price of the land. Since the investment in site preparation is large relative to the purchase price of the land, it is generally preferable to purchase, rather than lease, land in order to be able to recover development costs in the event of a later sale of the property. Thus, the MSDGC has decided to purchase its lands in Fulton County. The procedure used in the land purchases was to have the land appraised, enter into negotiations with owners, and finally to consummate the necessary purchases. Initially, strip-mined land in Fulton County was valued at $300-350 per acre, but land values have since risen to $400-600 per acre. The MSDGC has purchased about 10,000 acres to date, but this is not enough to fully assimilate, on a steady-state basis, the large quantities of sludge produced in the metropolitan Chicago area.

The foregoing description of the MSDGC's current operations in Fulton County suggests that the MSDGC has always chosen the operational alternative of purchasing, developing, and operating upon its own land. In Fulton County, the MSDGC has indeed purchased and developed its own land, but a substantial portion of the agricultural operations are contracted to local farmers. Only operations directly related to the application of sludge to the land are directly controlled by the MSDGC. The MSDGC has selected this alternative because it has found that the lowest long term cost and strictest operational control can be obtained through this technique.

However, the MSDGC has not always been committed to the alternative of purchasing and developing its own land. In 1971 the MSDGC chose to contract for a complete package of land acquisition, development, and operation. The MSDGC awarded a contract on such a basis to remove, transport and utilize liquid sludge in Douglas County, Illinois, about 150 miles from Chicago. The MSDGC's contractor successfully applied thousands of tons of sludge to agricultural lands and generally performed in a manner acceptable to the MSDGC. However, the relatively small scale of the operation relative to the MSDGC's total needs, and the contractor's legitimate requirement to operate at a profit and provide a contingency against unforeseen circumstances, combined to result in relatively high unit costs for the land application operation.

The final operational alternative to be discussed here is the option of delivering sludges or effluents directly to the farmers who would apply them to the land. This alternative has not been employed by the MSDGC, but could become a significant option in future years. In Illinois, the Illinois Environmental Protection Agency (IEPA) requires that any person or organization applying sludges or effluents to the land do so in accordance with a carefully planned and documented program and to obtain a State Permit for the operation. Presently, farmers are not required to submit any plans, or to obtain permits, for the application of commercial fertilizers. Without substantial economic subsidy, few farmers would, therefore, be interested in applying sludge or effluents to their lands, particularly after consideration of the fact that commercial products have substantially better fertilizer properties per unit weight than do sludges or effluents. Furthermore, the individual farmer is primarily interested in applying fertilizer at the least cost and in such a way as to maximize his yield. Application of sludges and effluents must be carried out in relatively small dosages over the entire growing season in order to avoid uncontrolled run-off and reduce soil erosion. In cases where sludges and effluents are applied directly by farmers the difficulty and cost of maintaining proper control of the many scattered land areas would be substantial. Manpower costs for monitoring non-contiguous sites would be great, and design and construction costs for a multiplicity of independent systems would certainly be larger than for a smaller number of larger systems.

Political Alternatives

The political organization alternatives for large scale land application programs are:

a. Single local government control.
b. Combined urban government-rural government control.
c. Regional government control.
d. State control.
e. Federal control.

Single local government control is possible by either urban or rural local governments. In the case of urban governments, the above discussion has described how the growth of suburbs and the high costs of land tend to prevent the development of a large scale land application program within an urban area. It has been concluded that an urban producing agency must have access to large acreages in rural areas. Also, it is impractical for an urban government to exercise exclusive control over a land treatment program in a rural area without the local rural government being given a large share of control. At the least, the rural government must be granted the degree of control necessary to secure its acquiescence. On the other hand, it is unlikely that a large scale land application program could be controlled by a rural government alone due to insufficient financial resources.

Combined urban-rural government control appears to present a practical means to overcome local rural resistance to acceptance of what can often be a controversial program. Intensive educational programs will be required to earn acceptance of the concept of receiving and applying urban wastes on the land. Formation of a formal association between the urban and the local rural government serves to foster acceptance of land application programs. Therefore, it is believed that the participation of local governing bodies is indispensable in any program involving deposition of urban materials in rural areas. Although association between urban and rural government is a minimum requirement, it is more desirable to find a means of offering a more active and involved role to the local government. For example, direct participation in planning, construction of facilities, application of effluent or sludge to the land, monitoring, farming or some other aspect of the operations could be undertaken by the rural government. The financial support for such rural government activity could be by State and Federal Grants or by contractual arrangements with the urban partner. Granting a more active role to the local government in the creation of parks within the treatment area to provide facilities for sports and recreational activities is considered essential.

The MSDGC land application program in Fulton County has been developed with the assistance of a steering committee comprised of local elected officials, local citizens, representatives of State and Federal agencies, MSDGC trustees and staff personnel. The mutual goals of both the MSDGC and Fulton County, as well as the comprehensive approach to site development, were published jointly by the MSDGC and the Fulton County Board of Supervisors. The steering committee recognized that although the land in Fulton County was purchased for the primary purpose of applying digested liquid sludge to the land, the needs of the local communities would be integrated into the plan with compatible secondary goals of recreation, conservation, natural science education and economic stimulus. The Fulton County Planning Commission has approved the multiple use planning of MSDGC properties located in that county. The MSDGC leases over 400 acres of its property to the Fulton County Board of Supervisors for development of fishing, camping, boating and picnicking activities. In short, the "Prairie Plan" is an example of combined urban-rural government cooperation in the development and management of a land application program for their mutual benefit.

Regional government control may be useful in areas where there exists an urban source of effluent or sludge in proximity to a land area suitable for application of these materials. The Muskegon County, Michigan, project is of this sort. It is designed to process almost all the sewered wastewater produced in that county.

State or Federal control of a large scale treatment program appears less of a possibility than the types of control so far discussed. Both the states and the Federal government are reluctant to assume responsibility for projects that can be carried out by local governments. However, preliminary surveys of five urban areas have been carried out by the U.S. Army Corps of Engineers. One of these areas, the Chicago-Northwest Indiana Region, crosses state boundaries. To implement a land application program in this region would almost certainly necessitate the creation of an interstate regional authority. However, there would not appear to be anv rationale for direct Federal control.

Legal Constraints Affecting Alternatives

Land application is not a new idea insofar as wastewater treatment is concerned. The Chinese have been fertilizing their fields with "night-soil" for centuries and municipal wastes have been applied to farmland in Europe since the sixteenth century. However, the use of treated wastes, as, for example, effluent from a secondary wastewater treatment plant or stabilized digested sludge, is a fairly recent practice. Accordingly, there has been a lack of complete development of laws, statutes and legal principles governing land application activities.

An evaluation of Federal and State laws, standards and guidelines pertaining to land treatment appears in "Green Land-Clean Streams", published by the Center for the Study of Federalism of Temple University. The latter publication reviews the development of water legislation bearing on land treatment. At the time of publication (1972), there was no Federal water legislation of this type, but many of the states have had various regulations, guidelines, and policy statements since the 1930's. Since publication, the Federal Water Pollution Control Act Amendment of 1972 has been passed by Congress and signed into law. It contains various references to land application of sludges and effluents. For example, in Section 107, it calls for projects to control mine water pollution, including techniques of using sewage sludge materials to restore affected lands to usefulness, to be carried out with the cooperation of the States.

In the State of Illinois, the Environmental Protection Act of 1969 created the Illinois Environmental Protection Agency (IEPA) to administer the Act, and the independent Illinois Pollution Control Board (IPCB) as a rule-making body. No standards for land application of effluent or digested sludge appear in the "Water Pollution Regulations of Illinois." The Standards Section of the IEPA is currently using the standards for land treatment published by the Great Lakes Upper Mississippi River Basin States in Addendum No. 2, 1971 Edition. This Addendum fails to admit the existence of land treatment facilities of substantial size, especially outside the GLUMRB region, and states that "protection of groundwater and surface resources is the major concern in the development of guidelines" for the filing of an application for a permit to operate a land treatment facility. Until now, the IPCB has specified that the effluent from the run-off holding basins must meet effluent standards as given in Part IV of Chapter 3, "Water Pollution Regulations of Illinois." The IPCB's decision to impose effluent standards on run-off from sludge or effluent application fields, while not imposing similar requirements on run-off from normal farm fields, is criticized by the editors of Temple University's "Green Land-Clean Streams".

Other legal constraints exist. For example, in the case of an MSDGC contractor carrying out land application of digested sludge in Grundy County, Illinois, that county attempted to terminate the project on the ground that the contractor had failed to obtain a permit from the County Zoning Board. Since the zoning regulations explicitly stated that they did not apply to agricultural facilities, the matter was brought before the Courts. A decision was rendered in favor of the land application project, classing it as an agricultural operation. It remains to be seen whether or not this decision will bring about a revision in the IPCB regulations, that now classify run-off from land application projects as effluent instead of normal agricultural run-off.

Finally, as exemplified by the IEPA Permit issued to the MSDGC in connection with the Fulton County Project, large-scale land application of effluent or sludge is considered to be a new procedure, still experimental, and subject to modification or termination if it results in or threatens to cause pollution of waters, air or lands, or hazards to water supplies. Furthermore, the IEPA has stated that it is not in a position to guarantee the legal validity, under Federal law, of its permits for the disposal of sludge by any operation that might "result in any pollutant from such sewage sludge entering navigable waters".

Thus, land application systems are characterized by many legal constraints. Development of a satisfactory land application program for effluent or sludge will necessarily be greatly influenced by the nature and extent of these constraints.

RECOMMENDATIONS

Land application of effluent and sludge is still in a developmental stage. Demonstration projects are required to develop new technology and resolve certain technical problems. There is a great need for substantial State and Federal assistance in the area of research and development. Not only is financial assistance required, but, in order to prevent overlapping and duplication of effort, it would seem appropriate for governmental agencies to plan and coordinate research and development, and perhaps, to carry out such programs under the auspices of existing government institutions. Such agencies have at their disposal resources that are unavailable to even the largest producers of sludges and effluents.

In addition to support of research and development programs, there is a need for a greater measure of Federal and State commitment and positive encouragement of land application programs. Laws, regulations and guidelines should be revised to facilitate, not discourage, such programs and should recognize that they constitute not just an approved method of treating wastes, but a necessary and preferred method.

There is a need for comprehensive land use planning on a state-wide or regional basis. Large tracts of land could be developed to accommodate numerous public facilities normally considered undesirable. For example, airports, land fills, sludge and effluent application areas and wastewater treatment plants could be accommodated on large common sites. These tracts could be made attractive and could upgrade and preserve local natural environments by providing public parks and forests, complete with nature paths and camping and recreational facilities.

CONCLUSIONS

The problem of sludge and effluent disposal is becoming more and more pressing with time. For example, as primary wastewater treatment becomes inadequate and is succeeded by secondary and then by tertiary treatment, sludge volumes throughout the country are increasing. The assistance of the Federal and State governments will be necessary in developing adequate land application programs. Land application, now in a developmental stage, will require demonstration projects to introduce new technology, resolve technical problems, and win public approval.

It has been pointed out that an agency interested in land application will be most successful when it operates in a manner acceptable to the local population of the receiver area and when it has engaged local government in direct participation in the project. The most significant hurdle in the successful initiation and operation of a land treatment program is public acceptance. Also necessary is the ability to work with a variety of public agencies and competing interests.

The favored method of handling land acquisition has been seen to be by purchase, preferably of large tracts. Acquisition by lease has been found to be generally undesirable. It would appear that the most feasible approach is to purchase a sufficiently large parcel of land to minimize design and construction costs and the cost of control and monitoring.

As noted, public opinion and the diversity of public agencies involved make the success of land application programs subject to considerable uncertainty. Federal intervention may be necessary to provide a consistent governmental approach to this problem and make it possible for the land application agency to free itself, to some degree, of unnecessary unconstructive forces.

DISCUSSION

QUESTION Bob Miller, Ohio State University. Your comments on the prairie plan about the fact that large treatment systems cannot get the agreement of the people within the metropolitan system, this is contrary to what we are finding in Ohio on the Three Rivers Water Shed Study by the Corp of Engineers. There it seems that acceptance of effluent disposal on land within the basin, the Three Rivers Water Shed is fine, acceptance outside of the basin where one of the alternative plans designated disposal has met with a great controversy and probably is not even feasible. So, I think there are situations that are totally different and each one will have to be handled by itself. We came to the conclusion that acceptance by people of their own wastes is better than acceptance of other peoples waste.

ANSWER: I think I would agree with what you have to say. I would like to emphasize though, that in the case of the Chicago system the sludges that we are applying to the land are certainly outside of the jurisdiction of the Metropolitan Sanitary District. They are some two hundred miles away, so here we are not in a situation that people are not accepting their own wastes, but they are seen as accepting the wastes of some other area. But I certainly would agree that each area should be analyzed on its own merits.

Public Acceptance— Educational and Informational Needs

JOHN O. DUNBAR
Purdue University

INTRODUCTION

For an idea such as recycling urban sewage and sludge to the land to be implemented in our society, it must have public acceptance. It must be acceptable to the majority of the people. It must be actively supported by a large enough number of individual leaders so that they can favorably inform the people who depend upon them and keep those who oppose it in the minority. It must have enough support by both private and public groups so that they will use their organizational, financial, and political strength to bring about its implementation.

I believe we can all agree that the level of public support for this idea at this time (July 1973) is a great deal less than is needed; therefore, we need to devise ways to raise it. The question we face is how can this be done most efficiently with our limited resources. It is a question of changing people's behavior and developing effective programs to bring it about. *Therefore, the basic problem we are concerned with in this discussion is how to get people to think, feel, and act more favorably toward recycling urban effluents and sludges to the land.*

If this idea is to be accepted, we must secure for it a higher place in the mind and active effort of many people. Large numbers of people must become aware and concerned. They must be informed about why it is being considered over other alternatives for disposing of sludge; how it will work; its consequences in terms of such things as dollar costs, effect on health, and on agricultural production.

People must feel positive and *not* negative. They must feel supportive of the idea, that it is progressive and *not* regressive, that it will result in a net gain in environmental quality, and that it is worth the extra costs entailed. Feelings of uncertainty and suspicion must be replaced by reliable factual information and analysis. Feelings of frustration and hostility must be replaced by feelings of mutual trust and dedication to the common goal.

People must be willing to *act* differently. For this idea to be adopted, decisions must be made and actions taken to support it. Clear thinking and warm, positive feelings are not enough. Those already in favor of the idea must be willing to work out compromises and publicly supported technical and financial assistance and retribution for those whose property rights are damaged, all of which may be necessary to win acceptance. Local, state, and federal agencies must cooperate to get the largest public good for the least social and economic cost. Elected representatives of the people must provide legislation which both exercises the will of the majority and protects the rights of the minority. And local leaders of various interest groups must be brought together to find ways to either make this idea work or find a better alternative.

How do we bring about these changes in behavior? For this analysis, I shall draw upon the works of Dr. Gordon Lippitt, an outstanding psychologist, and Dr. Ralph Tyler, nationally recognized educational theorist and behavioral scientist plus my own experience and study of public policy education.

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Why People Resist Change

First, let's look at Gordon Lippitt's analysis of why people resist change. In brief, he says that people resist change under the following conditions:

- When the purpose is not made clear—mystery and ambiguity cause suspicion and anxiety. If people can't tell where you'e going, they may be reluctant to join you for the trip.
- When they are not involved in the planning.
- When an appeal is based on personal reasons (yours, not theirs).
- When the values, norms, and habits of the people are ignored.
- When there is fear of failure, i.e., that the goal may not be reached with the funds available.
- When the cost (social and economic) is too high in relation to the benefits or when they believe the costs of an alternative method would be lower to secure the same results.
- When the present situation seems satisfactory. Why upset the applecart?
- When they think they may have to pay the costs for benefits someone else will receive.

We all know that people with vested interests may be very hard to sell on this idea. They may not only be hard to sell but able to block its implementation almost indefinitely, especially if the public feels that they are being treated unfairly or unjustly. Take for example the farmer who may have heard that someone is planning to spread city sludge on his farm. He is not only aware but hostile, fearful, and concerned about what will happen to his land and his family. If this farmer's interests aren't considered and he isn't involved in the planning or if he's treated arrogantly and unfairly, the public and legislators who represent him may decide that equitable and just treatment for him is more important than clean water in a river. Public opinion usually favors an underdog. Also, he may know not only his commissioner and councilman and his State representative and State senator but also his congressman, his senator, and the governor. A surprisingly few such people can block a seemingly good idea for a long time.

Overcoming Resistance to Change

Turning this coin over and looking at it from the positive view, we have learned a great deal about how to reduce resistance to change (e.g., to recycling urban sludge to the land). Some of the principles are as follows:

- Involve the people in the diagnostic and creative processes of decision making—they tend to understand and support what they create.
- Allow the people to blow off steam. Too often people pushing an idea try to move ahead "so fast that the opposition won't have a chance to organize." These famous last words show lack of appreciation for the principle of "catharsis"—to relieve emotion so that objective discussion and deliberation can take place. Don't fear it! Encourage it!
- Be certain that people agree upon the goals and reasons for the change. Clarify the whys and wherefores.
- Build a trusting climate—tell the truth; maintain open communications; don't spring decisions on them; develop mutual respect.
- Provide the information needed for people to think intelligently. This provides the basis for people to make sound decisions.
- Provide an opportunity to grow (through greater knowledge of the environmental quality problem and what would happen if we were to recycle urban sludge to the land).
- Provide meaningful rewards—self-expression, recognition, opportunity to acquire new knowledge.
- Keep people informed. They will get more intimately involved if they know the latest details.

A moment's reflection tells us that these are all really quite common-sense ideas. Our own experiences in dealing with our friends, our families, the people with whom we work, and the public lead us to these conclusions.

Helping People Acquire New Behaviors

We, who wish people to change their behavior, cannot get them to do so by saying "You ought to think, feel, or act differently" unless they hold us in the highest possible esteem. Neither can we coerce them into it. What we can do is provide various stimuli which hook their interests or concerns. Then, after they become more intellectually or emotionally involved, they will behave differently; and when various segments of the public behave differently—we hope more positively—toward recycling urban sludge to the land, we will have achieved our goal.

Now let's turn to Dr. Tyler. He says that:

- New behavior is acquired only when practiced and when the person receives satisfaction from it. This stimulates him to repeat his ways of thinking, feeling, or acting, and to go further. Behavior which gives us satisfaction is continually repeated, while that which is not satisfying is quickly dropped.
- To acquire new behavior, the person must be involved; must put something into it.
- For carryover of behavior to take place, the person must perceive a connection between what he

is learning and how it affects his own life, e.g., provides a safer environment.

- Change is more rapid when people get information from a variety of approaches in which they can see common elements in a variety of situations.
- Each idea and relationship must be within the person's ability to perceive at his level of interest, concern, and knowledge.

Dr. Tyler's principles for helping people acquire new behavior are understandably very similar to those of Dr. Lippitt. They are as follows:

- Clarify the behavior you seek to develop in the individuals. Only when we know the behavior we wish to influence can we plant our information and educational program effectively. With reference to recycling sludge to the land, what behavior do we wish to stimulate? Examples are: (1) Do the people lack interest? If so, the behavior we need to develop is "greater interest." (2) Do the people need to develop an attitude of concern for public welfare? If so, we need to help them see the effects of pollution on our rivers and lakes. (3) Are they familiar with the various methods of dealing with the problem (urban sludge in this instance)? If not, our goal should be to acquaint them with what the choices are. (4) Do they need greater ability to predict probable consequences of alternative methods of disposal of sludge? If yes, we need to provide them with the information on what would happen if we were to implement various alternatives (how they work, costs involved, benefits, who pays the costs, who benefits).
- Stimulate the people to react. Let the people know what is being considered from the earliest possible moment (via any media). New knowledge of this type immediately turns on people's intellectual curiosity, triggers analysis. In dealing with the public, we are too often fearful of what people will say so we put off this stimulation and slow down the development of public opinion. If "catharsis" is needed, it is better to have it in small doses than in upheavals of public opinion.
- Guide the people's reaction, not by telling them what they ought to do, but by focusing their attention on points they can perceive and helping them move from point to point until they have the whole picture. A well-planned program should help them have the same experiences as people who think, feel, and act positively towards this idea.
- Provide satisfaction with resulting behavior, e.g., provide a forum for leaders to express their thoughts and feelings or publicize what they have done.
- Organize the educational program so that the individual can relate what he is doing in some other area of his life with recycling of urban sludge to the land, e.g., for the public—its effect on food production; for the farmer—its effect on corn yields. Any important change in behavior takes time; and the more quickly this integration take place, the more rapidly will public opinion be formed.
- Make continuous appraisals of what the public (various parts of it) is thinking, feeling, and doing concerning this idea. This is done by conversation, observation, and the use of planning committees.

A Proposed Educational and Informational Program

On the basis of the problem we face in winning public support for recycling urban sludge to the land and the principles of behavioral change outlined above, let me propose an Educational and Informational Program. In developing such programs, we face five fundamental questions.

Whom specifically are we beaming the program toward?

Who are the target audiences? Different segments of society have different interest levels, differences in prior knowledge and understanding, different vested interests, and different concerns. So for greatest effect, we approach each of them in a different way.

For this program, I identify four major audiences: (1) The uninterested general public, (2) Decision makers and others already concerned about the environment and different ways of handling urban sludge, (3) People with vested interests, and (4) Professionals from government agencies and institutions who work directly with the people who will be most affected by this decision.

What behavioral changes do we wish to bring about in each segment?

- Awareness and interest.
- A decision to believe in an idea.
- Active engagement in support of the idea.
- Involvement in modification and innovation to put the idea into effect.

Differentiation in interest and knowledge among various target audiences make it necessary to concentrate on behavioral changes appropriate to each. Also, mass methods and media are most effective and economical for some behavioral changes, while face-to-face is best for others.

What information is needed to capture the attention and interest of the people in each audience and to bring about the desired behavioral change?

It takes different information to interest the public-spirited citizen not directly involved than it does to interest an irate farmer who has his mind made up that "They're not going to dump that city sludge on my land!"

Also, it is important to figure out exactly which information is needed by the audience concerned so as not to bore people with something they already know or waste time and money trying to "teach them more than they want or need to know to change their behavior."

What are the best educational methods for bringing about the type of change desired?

What is the best means or media of communication with the target audience?

Now let us summarize the educational program for each target audience.

1. *For the general public:*

a. *Behavioral changes we seek*—greater awareness, interest, and concern about recycling urban sludge to the land.

b. *Methods*—clarify goals. Attach a new interest (recycling sludge to the land) to an old one (reducing pollution of the water). The public knows that people in cities and towns are going to continue to produce sewage and that it must be disposed of some way. They also know that it is impossible to use septic tanks and disposal fields for large concentrations of people. They know that sewage goes into sewers. Beyond that, they don't know much—nor do they care, unless sewage disposal becomes a problem—which it has.

c. *Means of communication*—news releases and feature stories in mass media (TV, radio, newspapers magazines) and speeches.

2. *For decision makers and others concerned about the environment and different ways of handling urban sludge:*

This includes lay leaders, legislators, elected officials, interest groups, and leaders of various institutions serving the public.

a. *Behavioral changes we seek*—active support for recycling sludge to the land.

b. *Methods*—broaden the base of knowledge and understanding about ways of handling sludge and the consequences of each. With this knowledge, people can make choices based upon their own value system, which hopefully already includes a desire for cleaning up the environment. They must be given comparative knowledge about all the alternatives, among which are:

- Recycling sludge to the land.
- Recycling sludge to the lakes and rivers.
- Other.
- Other.

By far the simplest way to get people to look favorably upon one alternative is to let them compare it with others so that they can tell which they deem most desirable. This takes some courage on the part of professionals and planners—and some faith in the judgment of the public. But if we don't have that, we haven't much faith in democracy.

For each alternative, we should also provide an analysis of such things as:

- Dollar costs in terms of aggregates for a city, or per capita, or some other meaningful figure.
- Where the money comes from to pay the costs.
- Effect on the environment to which the sludge is being recycled. Include the physical, biological, human, and economic effects.
- Effect on human health.
- Other.

c. *Means of communication*—being somewhat difficult to present, emphasis should be given to face-to-face contact where possible in lectures, symposia, forums, and seminars. People need opportunities to discuss this with experts. Carefully prepared pamphlets, leaflets, feature stories are excellent supplements.

3. *For people with vested interests:*

This includes legislators who must prepare legislation, public officials whose duty it is to make decisions, and citizens who will be significantly affected.

a. *Behavioral changes we seek*—favorable action, reduced criticism.

b. *Methods*—include them in the formulation of decisions, working out compromises, finding better alternatives, and compensating those hurt by the decision. Even though most of this group of people has a vested interest to protect, they also know enough to realize that sludge must be disposed of some way and that ways must be found to keep the environment clean.

c. *Means of communication*—personal contact, individually or in small groups, through which thoughtful discussion can take place works best. Means include (in order of effectiveness):

- Inclusion in decision-making groups.
- Advisory committees.
- Public hearings.

It should be recognized that many of these people have a positive attitude, excellent minds, and great knowledge with which to supplement the brainpower of the professionals. They are in some ways a free resource.

4. *For the professionals from federal, state, and local government agencies and institutions who work closely and directly with the people affected by the decision:*
   a. *Behavioral changes we seek*—greater knowledge, favorable attitudes, active support.
   b. *Methods*—involvement. They know a great deal about the people on whom the decision will impinge and have a great deal of information at their fingertips to contribute to the educational processes necessary to win public support. And they have a desire to help.
   c. *Means of communication*—personal contact, seminars in which all "agencies" are included.

CONCLUSION

I believe a great deal can be accomplished with an educational and informational program to win public acceptance of recycling urban sewage and sludge to the land. In order to use limited resources efficiently, such programs should be carefully thought through and analyzed. Necessary information should be developed and disseminated as quickly as possible. We should remember that the changing of public opinion takes time. For the people to acquire information and change their ways of thinking, feeling, and action is a slow process. Remember—*Leadership consists of getting people to do what you want them to do because they want to do it!*

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Some Extension Service Capabilities

CHARLES P. ELLINGTON
University of Georgia

I appreciate the opportunity to take part in this conference and to expound on some of the strengths and some of the limitations of the Cooperative Extension Service.

The Cooperative Extension Service is almost 60 years old. We were created by an Act of Congress in 1914 and given the responsibility to take the findings of research from the Agricultural Experiment Stations and to extend those findings to farmers and others who could put them into use. We have been known primarily for our work in agriculture and secondary for 4-H and home economics. Our role in community development is new to us, and nationwide we now expend about five percent of our total resources in this area.

There is a Director of Cooperative Extension at each of the Land Grant Universities. There is also an office in virtually every county in the United States. Each state has a staff of specialists who provide the back-up on technical subject matter to the county agents. Among the specialists you will find Agronomists, Poultry Scientists, Nutritionists, Economists, Horticulturalists and others. You will also find specialists in industrial development, manpower, recreation and several other disciplines. We also have the capability, in most states, of calling upon experts from other areas of our state universities—for example, in business administration, law, pharmacy, social services and others as needed.

As you would expect, we have learned a few things in our 60 years of experience. One of these is to stimulate interest and to provide information but to leave the decision making to local people. This is a cumbersome, slow, and on the surface at least, an inefficient way to conduct an educational program. But it works and it has allowed the Extension Service to gain credibility in most communities that is seldom found in the programs of any other agency of State, Federal and local government.

Extension is frequently asked to "legitimize" or "sell" a program for one agency or another or as Dr. Dunbar addressed the topic "gain public acceptance". I can't speak for all Directors of Extension but I can speak for myself and my experience has been rather sad in those instances where we undertook the job of doing someone else's educational or informational program.

In the first place, to most agencies the term "education" really means information or selling and not really education at all. Extension education to me means discussing all the possibilities—all the pros and all the cons and then allowing people to decide for themselves. This means that we can stimulate interest and we can provide information but we should not become the advocates of any agency or of the programs of any agency.

In the second place, we are in effect trying to "close the gate after the horse is out". People should be involved and informed before decisions are made and not after someone in authority has already decided what should be done and how it should be carried out.

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But here are some things we can do:

1. Through the county offices and the county rural development committees, Extension can locate and identify the leadership in each county. It is this local leadership that must be stimulated, informed, and mobilized in order to gain local support and action.

Extension is in a better position to accomplish this than anyone else that I know.

2. Extension can provide resources to help deliver information to the leadership which has been brought together.

Remember the original charge given to us in 1914 was to disseminate information—not necessarily to originate it (although in some cases this has been necessary) but most often to "translate" and pass on research findings in a usable, understandable form.

In most states, we will not have all the expertise needed to disseminate information regarding sludge disposal. But we do possess the ability to either work with other agencies or to acquire the needed manpower ourselves to complete the task. Most states will already have the soil scientists, the engineers and the economists—but may need to bring in the microbiologists, the systems analysts and others to complete the task.

The machinery or hardware for dissemination of the information already exists and with but slight modifications can be put to immediate use.

3. Extension can play the role of the coordinator or facilitator—we can call the meetings, we can arrange the programs, we can help to coordinate information from various sources and in so doing provide the stimulus needed for local citizens to become involved.

We welcome the opportunity to work with you on the subject of recycling municipal sludges and effluents—and in fact on any subject dealing with environmental quality—on a continuing basis.

Informal Opinions

CHARLES JELINEK
United States Department of Health, Education and Welfare

(An unscheduled report was given by Charles Jelinek, HEW Food and Drug Administration, Washington, D. C. His report was transcribed as follows.)

Rufus Chaney asked me earlier today if I would be willing to just give you my own informal opinions on FDA's outlook towards the use of sludge or effluents as fertilizer for either food or feed crops, so this is it. This is no official viewpoint at all because we don't have one. Our charter, in the Bureau of Foods within FDA, is to make sure the food that all of us eat, you and I and our kids and our grandchildren, don't present any unnecessary or unusual hazards to health. So, as an extension to that, we are interested in the use of sludge or effluents as fertilizers. We want to make sure that such use doesn't furnish any undue hazards in our food supply. I would say the main contaminents that we are interested in are the chemical contaminents, mainly the heavy metals but also organic chemicals. And then also the pathogenic organisms. One thing I want to stress right off the bat and that is that we are not out to stop the use of sludge or effluents as fertilizers for crops. We are interested in looking ahead to see or try to foresee what hazards there may be in foods. This is so that we can stop it right at the root cause before there is some full-blown crisis that is going to develop from some food that is being grown in some producing operation. When that happens you have seizures and recalls, and believe me that is no fun for us and it is no fun for the people who are producing the food involved.

In regards to chemicals and heavy metals, the ones that are of main interest to us at this time in regards to contamination in foods are mercury, lead, cadmium, arsenic, selenium and zinc. Organic chemicals right now, mainly pesticides, PCB's are products of that type.

I would like to tell you a little bit about a couple of problems that are causing this concern now, because I think it gives you good background on our interests and our concern in regards to the use of sewage and effluents as fertilizers. In regards to cadmium, I would say right now neither we nor anyone else has really settled on a good estimate of what the acceptable daily intake is, and I might say that any time you see a figure of acceptable daily intake, that is nothing that is engraved in stone. It is a hell of an educated guess and that is about the best that you can ever do. But, anyway, based on oh, present estimates, primarily from Swedish workers, is that maybe two hundred micrograms per day of cadmium. There is a minimum amount that is going to cause damage to kidneys and I want to say right off the bat that we don't accept that as gospel, but right now it is about the best level to at least be used to guide our thinking. And probably in the diet, the average diet that an American adult eats, he is getting between 50 and 100 micrograms per day. So you can see we don't have very much of a safety margin. That is a two fold to a four fold safety margin. When you are talking about toxicology, that's really skating on thin ice. We are carrying out additional toxicological research on our own to try to arrive at some figure that we will have more confidence in or where there will be more background. But anyway, right now I would say our thinking and that of people in other countries and in a similar type of job is that there just isn't any room in the diet to have additional increases of cadmium coming along.

Now, in regards to lead, I can tell you one of the things we are faced with, and again this is just sort of an estimate, that for three to six year olds the maximum intake for lead per day that would be permissible, is around three hundred micrograms per day from all sources. Not only from foods but from eating paint and breathing in automobile exhaust and so on and so forth. From data that we have and other people have in regards to the diets for small kids and infants, I can see that again we don't have much room for safety. And this is a problem that we are wrestling with right now. Again, I would say that anything that is going to lead to an increase of lead in the diet, and especially a diet that would be important for small children, is something that we just feel ought to be avoided at all costs.

I sort of feel like a temperance lecturer up here right now because I am exerting all of you and I really don't have any really good hard guidelines to give you. The only guideline we have on heavy metals is an action level of half a part per million mercury in fish. That one—our job of setting a guideline there was simplified by the fact that essentially all of the mercury that we get in our diet comes from fish. Milk, bread, meat, everything else, eggs, practically no mercury, so the problem is simplified. But when you get into things like cadmium or lead or arsenic or selenium, these occur in a lot of different types of foods. That complicates it. Also as we all know they are naturally occurring materials. So, some of the information that we have to develop before we can set any sort of action levels or alert levels or guidelines that are really soundly based require that first of all we do have to develop more toxicological information to give us a better idea just what the acceptable daily intake could be. Then, on the other side of the fence, we have to develop more information in regards to the level of occurrence of these various contaminents in foods for several reasons. One is to get a good idea just what the background level is. We would really look like a bunch of damn fools if we set up some action level for some contaminent and it turned out that the average natural occurrence level was higher than that.

The other is to get a good idea as to what the total intake is from all of our diet and also what the contribution of the levels of the given contaminent is rising from different food items. So, these are things that we have to do and right now some of our activities along these lines, in addition to the toxicological investigations, we are measuring levels of all six of these heavy metals I mentioned in the total or our so-called total diets survey which represents the average diet of the American adult and this is based on USDA information that they developed some years ago. At the same time we are developing similar information on pesticides. Also this fiscal year we are going to be determining the levels of these same six metals in fish. In lead, cadmium and zinc we are going to carry out a big survey on these three metals in 40 different food items, 20 canned and 20 non-canned. Among the non-canned items, just in the meat items I just might mention those, chicken, bacon, beef muscle, I forget whether that is chuck or roast or what, beef liver, hamburger and frankfurters. Also leafy vegetables such as lettuce and so on and so forth.

So, we hope at the end of this fiscal year we will have a lot better idea just what the level of these metals of concern to us are, not only in the overall total diet but in the major food items themselves. Based on that and additional toxicological information that we develop, then we finally will set some sort of action levels. But that is not going to be for any of these metals, just one level, say X parts per million of lead and for every item in food. I don't think we will have one single overall level. It will be different for different types of food.

Well, then, where does this lead us right now—in the types of operations we are talking about here where you are considering major new projects for using sludge or effluents as a fertilizer for either food crops or animal feed crops? We feel that in projects of this type you should carry out monitoring operations. More specifically ones where from the standpoint of testing you would grow the crops that you are interested in on test plots. At the same time control tests must be run with the same kind of crops and the same land using a commercial fertilizer and analyzed for these heavy metals I mentioned, also pesticides and also for pathogenic organisms. In the case of the metals and organic contaminents, if there is any increase, significant increase in levels, in the metals or organic materials, in the ones fertilized with sludge as compared to those fertilized with commercial fertilizers, I think that you ought to look at that very seriously and probably consider growing some other crop on it. That is about the only suggestion I can make at the present time. I wanted to have the chance to talk today because I know that a lot of this is controversial to a lot of you people, but I wanted you to have the chance to think about it so that when we get into our workshop discussions on Thursday, at least you can have your own thoughts gathered together along these lines.

Incidentally, you will notice I haven't said too much about pathogenic microorganisms and the main reason is that I am not a microbiologist myself and in this case I am just sort of speaking the views of other people in the Bureau of Foods, but they are very seriously concerned too that if these operations aren't monitored in the early planning stages to make sure we are not introducing pathogens into foods, that we could also run into trouble.

DISCUSSION

QUESTION: Al Page, University of California. Our last speaker mentioned a level in foods for lead of 300 micrograms per day per children, three to six year olds, I was wondering if he had a level for adults?

ANSWER: A figure of around 400 to 500 micrograms per day.

QUESTION: William Bauer, Bauer Engineers, Chicago, Illinois. Suppose that in comparing the crops grown on the sludge enriched soils or the crops grown on non-sludge enriched soils that you found the addition of sludge reduced the lead content for those particular crops, but let's say it went up for cadmium. What would be the view of the FDA on a case like that?

ANSWER: I would say we would say don't grow it because you have to consider each of these contaminents as an entity in itself. On the other hand, if use of sludge reduced the level of all of these contaminents as compared to a commercial fertilizer I would say that is all to the good. That would be fine. But ultimately when we set levels then that is what the level is going to be for the given food regardless of what is used as a fertilizer or whether the metal came from the tin can or from the meat grinder. When we find that level, well then that material gets seized or gets re-called from the market or something like that. So, all we are trying to do here is for all of us to look ahead and plan ahead if it looks as if there is some high level then, of course, for that particular metal the best thing is to try to cut it off at the source. If you have some industrial installation that is dumping its effluent in there that is high in this particular contaminent, may be you can remove it right at the source.

COMMENT: Rufus Chaney, USDA. One comment that I was unable to get in this morning and I think really needs to be made, is that there are some real benefits from these micronutrients in excess we find in sludges. The zinc and copper are frequently marginly sufficient or actually deficient in soils and the sludge, zinc and copper can be of meaningful benefit for putting sludge on land along with the other benefits that we see. The fact that many human diets, particularly some special groups, are zinc deficient already, (clinical zinc deficiency in big cities and teenage groups) shows that if we do anything with sludge to improve the zinc content of crops, it is a very meaningful benefit. So, I was hitting out again some things this morning, I want to let you know there are some real benefits and we aren't saying keep it off all together, we are saying spread it out.

CHAIRMAN: That is very simple. I wish we knew the answer.

Workshop Session Reports

The Research Needs Workshop was designed to achieve the objectives of identifying what is known about municipal wastewater effluent and sludge application to the land and what research is needed for successful application of such wastes to the land from economic, engineering, health, and esthetic points of view. The following ten Workshop Sessions were designed to achieve the latter objective:

1. Educational and Informational Needs
2. Public Health Aspects
3. Dimensions of the Problem
4. Land Resource—Sludge
5. Land Resource—Effluents
6. Plant Characteristics and Response—Soil-Nutrient Relationships, Crop Selection and Management
7. Plant Characteristics and Response—Toxic Chemicals
8. Options, Problems, and Economics—Engineering Systems
9. Options, Problems, and Economics—Agricultural Management
10. Political and Institutional Constraints

The participants of each workshop group were selected to represent a multi-discipline and multi-organizational approach to the task of identifying research needs. The individual results of each of the ten Workshop Sessions, including the list of participants, follow.

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WORKSHOP GROUP 1

Educational and Informational Needs

Many of the papers and much of the discussion emphasized the importance of public acceptance if a project is to succeed. Consequently, public affairs education is an essential part of any program concerned with the recycling of sludge and/ or effluent on land.

Our work group feels that the majority of the citizens should understand certain basic concepts of waste management if a successful educational program on recycling municipal wastewater on land is to be successful. They are:

1. The production of waste is a natural process.
2. Wastes are a part of a natural cycle; they contain organic matter, plant nutrient and other materials.
3. Wastes may be a valuable resource in the future to meet our growing needs.

Our educational researchers have explained how farmers accept new ideas and adopt new technology; perhaps the same processes apply to the wastewater recycling projects.

The acceptance of new ideas resulting in the application of new technology utilizes two interrelated processes—diffusion and adoption.

Diffusion refers to the spread of new ideas from the originating source to the ultimate users.

Adoption is a mental process through which an individual undergoes from first hearing about a new idea to accepting it and acting upon it. The diffusion/ adoption process may be subdivided into five stages. They are:

1. *Awareness.* The individual learns about a new idea but lacks sufficient information about it.
2. *Interest-Information.* The person becomes interested in the new idea and seeks more information about it.
3. *Evaluation-Application-Decision.* The individual mentally applies the new idea to his present and anticipated future situation and makes a decision either to try or reject it.
4. *Trial.* The individual applies the new practice on a small scale to validate its workability in his situation.
5. *Adoption.* The individual applies the new practice on a full scale and incorporates it into his management system.

At any point in the diffusion/ adoption process an idea may be rejected. Even after adoption of an idea, the practice may be replaced when another alternative is presented.

A major difference between the diffusion process and adoption process is that the diffusion occurs between persons and institutions while the adoption process is an individual matter.

Traditionally, Extension Service programs have dealt primarily with problems or issues in which individuals or a homogeneous group made the decisions and had the power to carry them out.

However, municipal wastewater is what we are concerned with at this workshop, and it requires group or multi-group action who may or may not have a common interest.

We must recognize that regional-urban wastewater and sludge management programs such as the Chicago-South End of Lake Michigan, Cleveland-Akron, Detroit, etc., requires cooperation between many governmental (Federal, State and local) entities, agencies and special interest groups—particularly local communities and farm groups far removed from the wastewater source.

Perhaps our prime educational research need is the development of techniques, methods and procedures for handling controversial issues between such diverse groups so the results can be better predicted.

Such an approach as Robert J. Burns, Extension Service, University of Missouri, has been using in conducting educational programs involving controversial issues called "Defusing" Public Decision might be adopted to urban wastewater land treatment programs.

The Bevens approach lists five steps:

1. *Define the problem.* The problem must be defined with sufficient generality to avoid argument over what is the problem. One way of avoiding this is to never define the problem in terms of a solution to the problem.
2. *List goals and values.*
3. *Develop alternative solutions.* Perhaps three to five.
4. *Explore the consequences of each alternative.*
5. *Leave the decision to the people.*

One of the keys to the success of the Bevens approach is early involvement of the various groups from the beginning.

As an example of the many groups that should be involved in an educational program, based on a proposed wastewater management study to be conducted by the Corps of Engineers for example, the Atlanta area, see the figure below.

1. The basic principle illustrated by Figure 1 is to involve opinion makers and interested people as soon as the study is authorized (pre-planning), meet with leaders, and keep the general public informed through the news media.
2. In developing the educational program let the leaders make the local leaders want to be a part of the decision-making process. Our society guarantees them this right.

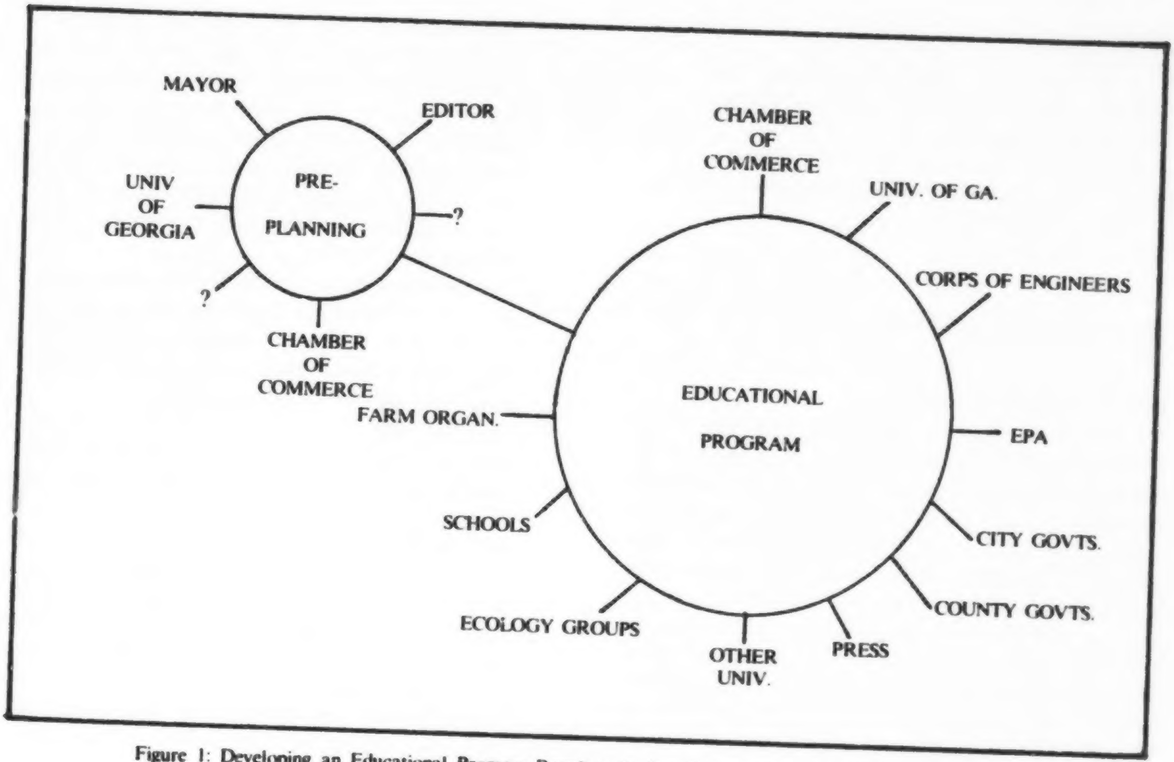

Figure 1: Developing an Educational Program Requires the Involvement of All Major Interested Groups.

In order to develop an educational program on recycling municipal wastewater on land, materials need to be developed on all phases of the problem—written material, slide sets, movies, etc.

Most people do not know that the two major components of wastewater is effluent and sludge—start here. An educational program of any value must start at the land of the level of the understanding of the people.

Materials should be developed which will explain the Federal Water Pollution Control Act Amendments of 1972, what they mean and their implications. These materials should include the goals and a schedule for attaining the goals.

Demonstrations should be developed which will have general application and they should come after the local leaders have generally agreed that an educational program has been developed that will work. The purpose of demonstrations is to show results.

The work group was favorably impressed with the land reclamation project which uses Chicago sludge in Fulton County. However, they offer the following suggestions which might be considered in similar projects.

1. Develop an attractive information center. Use slide sets or movies to explain the problem, the goals, and how they are to be attained. Also provide some kind of handout—a brochure which summarizes the project.
2. Demonstration area—keep it up to date, attractive, and readily accessable for observation.
3. The projects could perhaps encourage local lay groups to develop demonstrations to complement the project. For example, garden clubs might be involved in developing some plots on which flowers would be grown utilizing sludge. Perhaps these flowers could be used by them in their functions.
4. Provide a photo display of some of the bass caught from the lakes, wildlife, and ponds of the area and other recreation and camping attractions.

The selection of agricultural crops requires the expertise of many resource people from various agencies—Forest Service, SCS, Extension Services and the Colleges of Agriculture. These agencies' staffs contain many disciplines which are essential if the project is to be effective and if the public is to obtain a good understanding of the project. The project should not be confined to technical people, but should also involve public relations, recreational, and other groups who can contribute to the total educational effort and acceptance by the public.

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WORKSHOP GROUP 2

Public Health Aspects

Research needs on the public health aspects of the use of sludge or effluent on land were considered by our workshop to be dependent upon the point of view regarding the seriousness of pathogens in the waste.

One point of view was that since viruses and other pathogens regularly occur in sewage wastes, these wastes should not be distributed in the environment unless disinfected by pasteurization or equivalent treatment. Basic technology for achieving this pathogen decontamination exists, but research is needed to provide precise information on dosages of heat or chemicals for dependable and economical kill of pathogens in sewage sludges of all types. Detection methods need to be developed for detection of very small numbers of pathogens, especially viruses, in sewage sludges and effluents to assure effectiveness of pasteurization. For sludges, heat pasteurization is more feasible than chemical decontamination but research is needed to improve methods of measuring temperatures inside sludge particles where viruses may be protected. Methodology needs to be developed for improving chemical treatment of effluents supported by techniques for detecting low levels of pathogens in large volume of effluents. Methods must be developed for measuring a disinfecting chemical species in effluent systems being treated to be assured of adequate levels of the active agent. Improved techniques for measuring pathogens in soil and in aerosols are also needed to monitor disinfection practices.

The other point of view is that land disposal of treated sewage wastes has not so far been shown to be a greater health hazard than conventional disposal systems. Pathogens are known to survive the conventional treatments (e.g., secondary activated digestion, anaerobic digestion, liming), but their threat to public health may not be great enough to require disinfection by pasteurization or chemical means. At least there is insufficient data to show whether or not this is necessary. In this case research needs can be listed as follows:

1. The first priority research need is for comprehensive epidemiologic studies on human populations associated with both new and long-established land disposal systems. This would be studies on sewage plant workers and their immediate families. The objective of these studies should be to provide sufficient reliable data on health hazards of land disposal alternatives so that Federal, state and local health agencies can have a rational basis for uniform regulation and permits.
2. The second priority need, with either alternative, is better *monitoring* capabilities. There is need for improved methods of detection of both biologic and chemical pathogenic agents and for standardization of testing protocols.
3. An expansion of research is needed on dispersion of pathogens, especially viruses in aerosols, whether produced by spray irrigation of effluent on land or by various treatment practices in sewage treatment plants.
4. More basic research is needed on survival of enteric pathogens (viruses, bacteria and parasites) in soil, water, air when sludge or effluent is used. Movement of pathogenic agents through soil also requires more detailed study.
5. Since sludges and effluents may be applied to forages and pastures, more research is needed to determine health effects on livestock or on humans consuming livestock products from such treated fields.
6. There is general agreement that sludges and effluents should not be applied directly on human food crops and arbitrary waiting periods are usually imposed on sewage treated land before it is used for producing human food. Information should be obtained to provide a more accurate basis for establishing the length of this period before food crop production can be allowed.
7. We are concerned that expenditures for demonstration and construction of sewage treatment and disposal systems are not adequately supported by research components. It is recommended that grants for these projects include an adequate proportion of funds for research and monitoring.
8. Finally, it is recognized that there are also positive health effects on the nutritive value of crops produced on sludge and effluent treated lands. These beneficial features need to be fully considered in arriving at benefit-risk ratios for disposal systems.

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WORKSHOP GROUP 3

Dimensions of the Problem of Recycling Municipal Sludges and Effluents on Land

Statements of Fact/Observations

1. The 1972 Act recognizes that the treatment of sewage or sludge on the land is an acceptable form of treatment for municipal sewered wastes which must be considered as an alternative for Federally funded grants and the cost of the land used for treatment is eligible for grant reimbursement. Emphasis in the future should be on wastewater utilization and renovation and not on disposal. This is sometimes called the "4-R Cycle"—*Return* of wastewater to the local land; *renovation* of wastewater by soil and plant actions; *recharge* of groundwater resources; *reuse* of wastewater.
2. The volumes to be handled and the physical characteristics of sludges and effluents are sufficiently different to require separate recommendations and guidelines in many cases.
3. Parameters controlling use of the land depend upon local conditions including soil types, drainage, groundwater geology, climate, type of sludge and other local constraints.
4. Public acceptability is the primary factor limiting land treatment of effluents or land utilization of sludges.
5. Nearly all soils can accept some sludge and where land utilization of sludge has public acceptance today the costs are significantly lower than other alternatives. The process thus satisfies the cost effectiveness criteria required by law.
6. A large fraction of the population has land suitable for a sludge utilization within a reasonable and feasible distance.
7. The segment of the population which can be served by sludge utilization on the land is the segment which has access to regions which can be persuaded that sludge utilization on the land is acceptable.
8. Land application of wastewater *is not* an alternative to secondary treatment if secondary treatment is required as a pretreatment.
9. Land application of wastewater *is* an alternative to tertiary treatment for the removal of nutrients, suspended solids and some other pollutants. (It *is not* effective for the removal of soluble salts.)
10. The segment of the population that can be served by land application of wastewater is substantially less than the segment that can benefit from land utilization of sludge because on most soils at least ten times as much land will be required for effluent irrigation as would be required for sludge.
11. In water-short areas land treatment of effluents may be considered as part of the reuse cycle.
12. Small communities will probably continue to be the principle users of land treatment of effluents for the near future but stringent discharge requirements will make land treatment more attractive to large communities.
13. Research projects at Universities in recent years are influenced primarily by the sources of outside funds. There is a tendency for research on cause and effects to be superceded by demonstrations of processes.
14. Research and development priorities in EPA, USDA, and other government agencies are decided centrally based on needs statements supplied at least in part by the various regional offices.
15. Work is done by:
    (a) in-house scientists and engineers,
    (b) contracts,
    (c) grants and,
    (d) cooperative agreements between agencies and/or universities.
16. Significant cooperation exists between individuals at the operating level, whether or not there are formal cooperative agreements between their respective agencies.

RECOMMENDATIONS

1. Limitations and restrictions on land utilization or treatment of sludges or effluents should be comparable with restrictions set on other permitted forms of discharge.
2. An immediate epidemiologic study of selected existing land utilization and treatment sites

should be carried out with appropriate controls to evaluate the magnitude of the health problem in comparison with other methods of treating sludges and effluents.

3. Research should be carried out on the historical and long term effects that can be measured at existing facilities which have been using effluent application or sludge disposal on the land for many years while recognizing that these existing facilities *were not* designed primarily for wastewater treatment or for research on land utilization.
4. Research should be directed toward assessment and prediction of groundwater quality resulting from land treatment of effluents or sludges.
5. Guidelines should be set on an areawide basis considering land capability and other local constraints.
6. Research on markets for effluents and sludges is needed.
7. Finally it is recommended that an inter-disciplinary committee meet periodically and publish task force reports on current research results of land treatment and utilization along the lines of the Workshop conference for Recycling Municipal Effluents and Sludges on Land, held July 9-13, 1973 at the University of Illinois.

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WORKSHOP GROUP 4

Land Resources—Sludge

The objective of the workgroup was to develop a list of land resource related research needs to enable engineers to design feasible land spreading systems for municipal sewage effluents and sludges.

There is a considerable accumulation of information from research and experience that is useful. A great amount is known about the nature, location, and extent of soils and crops. Most soils are capable of assimilating sludges at a reasonable application rate with improvement in physical, chemical and biological properties resulting. Sufficient information is already available to design, with reasonable confidence, a land spreading system for small communities where light annual applications are made.

The following studies and activities are needed to plan and design land disposal systems in accordance with the characteristics of the land:

1) Nitrogen transformations with particular emphasis on development of techniques for controlling nitrogen leaching and pollution of groundwater.

2) Effects of various kinds of sludges on specific combinations of soils, crops and climates: (A) Long-term effects of heavy metal and organic matter additions; (B) Effects of applying advanced waste treatment sludges, physical-chemical sludges, and others to various soils; (C) Select standard crops, soil parameters and methods for determining parameters to facilitate comparing systems and evaluating their effectiveness; (D) Develop soil management technology to control metals in soils.

3) The effect of soil properties, climate, and land use upon fate of pathogens and parasites applied in sludge.

4) Crop selection and development of practices for optimum land management and waste renovation.

5) Study a minimum of twelve soil-climate-crop combinations to establish benchmarks from which guidelines can be developed for all soils and locations in the country.

6) Improve technology of renovating unproductive soils with sludge.

7) The effects of adding sludge borne salts in relation to soils and climate.

8) Establish technical assistance teams to help communities evaluate and establish sludge spreading as a disposal method.

9) Determine the soil and geologic factors that influence the rate of movement of leachates through soils, and the rate of diffusion and dilution in groundwater.

10) The feasibility of combined sludge and effluent spreading as related to soil and climatic factors. (Example—follow sludge spraying with effluent in semi-arid areas to rinse sludge from foliage, flush irrigation equipment, and leach salts from soil).

11) Develop complementary field treatment schemes such as small nitrification basins to be used with storage lagoons to achieve denitrification.

12) Compile a report of the amount of land within 200 miles of major metropolitan areas that is suitable for sludge spreading.

13) Toxic gas production as related to soil properties and application rates.

14) We need a measure of persistant salts in sludge. Most of the conductivity is caused by ammonium bicarbonate and organic acids which will be lost. Perhaps we should ask then extract with boiling water.

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WORKSHOP GROUP 5

Land Resources—Effluents

INTRODUCTION

The charge to the workgroup was to define land resource problems needing solution for applying effluents to the land. Addressing this problem stimulated some recommendations of a general nature and some statements regarding topics which do not appear to be problems needing research.

The general recommendations are (1) common terminology and definitions should be established to reduce confusion, (2) an indicator technique for confidently establishing the presence or absence of harmful viruses would be a great aid to system evaluation, and (3) establishment of regional research sites should be considered as a method of developing designs for key climatic, soil, and vegetation conditions.

Topics which do not appear to need research in the general context of the land resource are the amount of land required or the availability of land which is suitable. Problems relating to these topics do exist but they fall within the scope of other workgroups.

The workgroup considered the land resource problems needing research separately for low rate systems—such as irrigation, high rate systems—such as recharge, and overland flow systems—such as spray - runoff. Similar research needs are common to each of the approaches but the relative importance varies between the approaches.

Two major research needs were identified for the low rate systems; these are (1) establishment of regional research or demonstration sites to determine design criteria for various soils, climatic, and vegetation conditions, and (2) the degree of pretreatment required to protect the public health and assure safe consumption of crops. (See addendum for further detail.)

The workgroup agreed that high rate systems require permeable soils, low suspended solids in the effluent to be applied, and prevention of runoff from the site. Research needs were listed for the following areas: (1) combinations of pretreatment, system management, and vegetative cover that promote nitrogen removal by denitrification; (2) the influence of climatic conditions on system operation; and (3) the influence of system aging on hydraulic efficiency and renovation efficiency. (See addendum for further detail.)

Overland flow for treatment of municipal wastewater is a relatively untested approach. For this reason it has many areas needing research. These areas are (1) the limitation of soil texture, terrain and climatic influences on site utilization; (2) the effects of pretreatment (wastewater), site preparation and site management on system performance; and (3) limitation imposed by aesthetic factors such as public acceptance or vector nuisances. (See addendum for further detail.)

The workgroup also feels that more approaches to land application will be developed and that combination systems will play a role in practical use situations. Research needs for such approaches would be similar to those already detailed for the above approaches.

Research Needs for Low Rate Systems

I. Degree of wastewater pretreatment necessary:
  A. To protect public health.
  B. To assure safe consumption of crop by animals and/or humans.
II. Establishment of regional research demonstration sites to determine design criteria for various soils, climate and vegetation conditions.
  A. Soils
   1. Evaluation of physical and chemical properties of soils in relation to their suitability for wastewater disposal.
   a. Utilization of these data for model studies to predict durability of the system.
   b. Utilization of these data for extension of the results from the research demonstration site for the design of full-scale operations within the region.
   2. Determination of wastewater loading rates for the region.
  B. Climatic Conditions

    1. Evaluation of the effect of climatic conditions (mean and ranges) on the operation (annual or seasonal) of the system.
  C. Vegetation
    1. Development of suitable crop management systems to optimize crop yield and wastewater use.
  D. Evaluation of effects on wildlife.

High Rate Infiltration Systems

Requirements: Permeable soil
Low suspended solids content in wastewater
Separate storm runoff

Research Needs:

1. *Treatment* — Optimum combination of treating wastewater before infiltration, during soil filtration, and after collection as renovated water.
    Nutrient removal
    Pathogen removal
    Increasing Carbon/Nitrogen ratio of wastewater
2. *Soil* — Relation between soil hydraulic conductivity and maximum hydraulic loading rate (different soils, wastes and climates.) Soil management to increase treatment efficiency (adding lime, incorporating organic carbon and other techniques for increasing denitrification or hydraulic conductivity).
3. *Vegetation* — Vegetation management to increase infiltration and stimulate denitrification.
4. *Geologic Substrata* — Design, management, and monitoring systems to protect native groundwater resources.
5. *Aging of System* — Effect of aging on hydraulic efficiency and renovation efficiency.
6. *Climatic Conditions* — Effect of rainfall and temperature on infiltration recovery during pathogen removal.

Overland-Flow Systems

Requirements: Impermeable soil which can be graded to achieve desired slopes up to about 8 percent

Needs:
1. Soil and terrain
    a. Types and characteristics
    b. Effect of percent slope and length of slope on treatment achieved
2. Climatic influences on microbiological activity
3. Aesthetics
    a. Public acceptance
    b. Vector nuisances
4. Site preparation and management
    a. Degree of preparation and maintenance
    b. Compatibility with other land use (such as wet land agriculture)
    c. Selection vegetative covers
    d. Treatment efficiency of process
5. Pretreatment required (none, primary, secondary)

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WORKSHOP GROUP 6

Options, Problems, and Economics Agricultural Management

I would like to begin with a background statement to place in perspective our concern with land treatment of municipal sludge and effluent. Municipalities should consider their total system for handling and disposing of effluent or sludge. Industrial firms can reduce water use and waste by in-plant changes in processes and equipment, bi-product recovery, reuse of water, and product mix. The municipality also has a choice of treatment systems. Waste treatment systems vary widely in the amount of sludge produced. A system evaluation should involve these objectives: a system which achieves low cost for the total system rather than any one component, maintains environmental quality and achieves public acceptance.

Our research proposals can be broken into several parts. The first is related to economic or technical modeling. The second part is technical information required for both economic analyses, and system management and operations. Third, management and institutional options are important factors. And fourth, regional and community effects should be recognized.

Modeling

Modeling needs involve developing, adapting and applying research methods and procedures to the study of the problems of land disposal of effluent and sludge. There is a need to update the data which is available and, throughout modeling, determine additional data needs. This process should involve development of an information retrieval system which would be useful to municipalities, as well as program administrators and researchers.

Modeling would assist in multi-objective planning and implementation. One objective may be to maximize profitability of the cropping production at a site. Another objective might be to maximize waste treatment at a site. A more likely requirement would be to maximize environmental quality with trade-offs between profit and waste disposal objectives.

Most research information and recommendations have been developed in a framework of maximizing crop production. We know less about production relationships as you move to higher and higher levels of sludge application with the associated higher levels of plant nutrients and organic solids. There are trade-offs between the concern for crop profitability, concern for waste disposal and concern for environmental improvement. Our modeling can provide information which will be helpful in trade-off decision making.

There is a need to evaluate the impacts of constraining sludge and effluent disposal operations, to conduct sensitivity analyses of important factors, and to conduct risk analyses. These analyses would be applicable to problems in choosing and managing a total waste treatment and land application system.

Land Treatment Systems

A second search area involves an examination of alternative systems to be employed in land treatment. Most of our systems use components taken from other operations. There is a need to develop new machinery and equipment, to evaluate economies of size, and to determine economic feasibility and cost effectiveness of various systems under a range of climate and soil conditions. Differences in land quality, site location, distance, climate and rainfall, are relevant variables in designing land application systems.

Management and Institutional Systems

A third area of research deals with management. Management has responsibility for organization and operation. Monitoring is important and can be a trade-off for site preparation. Run-off control reduces the need for surface monitoring but may increase groundwater monitoring requirement. Management analysis requires information on crop and livestock enterprises and how they can be selected to accomplish the objectives mentioned earlier.

In relation to crop and livestock enterprise selection, information on production relationships and nutrient control and their relationship to environmental improvement should be developed. Part of the management problem involves leasing arrangements and flexibility in leasing arrangements. Management, basically, is important in community relations. The comments on local community relationships are related to the management of these operations because they must be separated in a way that meets public acceptance.

Crop response information is very important. Factors affecting crop response should be evaluated for high application rates. Land uses are important in operating and managing land application sites. What are the effects of loading rates, pH levels, amounts of water, timing and scheduling, nutrient removal and soil mixing.

Site management is concerned with environmental effects. This calls for cost-benefit analyses, ecological changes, long term effects on soils and pest populations, long term effects on water quality and the importance of land reclamation to communities in the area.

We need to examine institutional options as they relate to incentives for farmers and communities to use land treatment for disposing of effluent and sludge. This would include cost sharing, taxation, community grants, pricing of water and sewer services and payment options. We need to examine land use regulations in relation to land treatment as well as methods of acquiring and controlling land, ownership, leasing, and easements. Transaction costs vary widely and would influence institutional options.

Regional and Community Effects

Regional and community effects of a large project such as Fulton will have an impact on income in the area. Large projects will affect employment, the tax base, and community facilities and services needs. Regional and community effects might be important to many communities and lead to adjustments. The regional adjustment implications of both large and small land application operations should be determined.

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WORKSHOP GROUP 7

Plant Characteristics and Response—Soil Nutrients

This workshop group on *Plant Characteristics and Response—Soil Nutrients* considered plant nutrients in relation to land application of sewage sludges and effluents only from the standpoint of nutrient aspects, while recognizing the importance of toxic element considerations; *those* considerations being the major responsibility of our sister workshop group on *Plant Characteristics and Response—Toxic Chemicals.*

Our group believes that we need:

1. Field testing of existing information to see if it is applicable to the concept of adding well-characterized effluents and sludges to well-defined soil-plant systems. This should include but not be limited to:
    a. Sewage organic matter decomposition rates and nitrogen and phosphorous availability.
    b. Denitrification.
    c. Phosphorous retention capacity.
    d. Movement of organic and inorganic P.
    e. Zinc and/or Zn-P interactions and Zn-Cd interactions.
    f. Boron in effluents.
    g. Manganese deficiencies.
2. Investigation of natural chelation processes.
3. Species identification and crop management for full or maximum nutrient utilization, particularly including species for use in forest and rangeland management systems.
4. Mathematical modeling of soil-plant-sludge and/or effluent systems.

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WORKSHOP GROUP 8

Plant Response - Toxic Chemicals

The overriding top priority research need concerning toxic chemicals is to develop criteria for concentrations of these chemicals in sludges that are safe for land use on a long-term basis. The list of specific research needs is divided into immediate and long-term needs, recognizing that both should be initiated and supported at the same time. The immediate needs are those that can provide short-term contributions to guidelines whereas long-term needs will provide final and more reliable criteria.

The elements of primary concern are Cd, Pb, Hg, As, Se, Zn, Cu, Ni and B, but others can be of importance in local situations or become important in the future. These elements are of top priority because of plant toxicities or because of potential food chain problems.

Successful completion of these listed research needs can lead to better management of the soil-plant system for reduced hazards from trace elements, can greatly improve interpretive soil maps for land use of sludges and effluents and can prevent serious mistakes in site selection.

Research Needs

A. Immediate Needs

1. Tolerance of adopted plant varieties to toxic elements and the accumulation of these elements in specific plant parts.

    Determining the tolerance of plants to toxic elements will indicate potential problems before they become economic considerations. The determination of the accumulation of toxic elements in plant parts that become part of the food chain is essential for public health purposes.

    The crops to be studied include the food, feed and fiber producing plants as well as forest crops, ornamentals and brushland species. Studies should include Zn, Cu, Ni, PO_4, NO_3, Pb, Cd, As, Se, Hg and B because of either toxicity to plants or because of potential hazard to animals and man.

    Accumulation of toxic elements in edible portions of plants in relation to climatic, soil and management factors are of primary concern.

2. Empirical studies of the effects of soil parameters on toxicities of chemicals.

    Impirical correlations of the toxicity of trace elements and heavy metals which such soil parameters as cation-exchange capacity, surface area of soil particles, pH and soil morphological characteristics are an immediate need. Such correlations can be useful to public and private agencies involved in selection of sites for land use and in comparison of land use with other disposal alternatives. The preparation of interpretive soil maps for uses of sludges and effluents can be greatly improved by assessments of the effects of soil parameters on element toxicities.

3. Methods of evaluation and development of diagnostic techniques.

There is an immediate need for rapid laboratory and greenhouse methods for evaluating the suitability of various combinations of sludges, crops and soils for land use. Also, laboratory diagnostic techniques for measurements of availabilities of toxic elements in soils and for toxicities in plants need to be developed. These methods when standardized using characterized soils and sludges can have utility in site selection and in monitoring sites after land use has begun. Rapid laboratory and greenhouse indeces can be as useful in elucidating toxicity problems as they have been and still are in evaluating deficiencies. Standard samples of soils, plants and other materials should be used to provide reliable comparisons of analytical results obtained by various laboratories in research and monitoring programs.

B. Long Term Needs

1. Effects of toxic elements on yield, nutritional and product quality of crops grown on land treated with sludges and effluents.

Research is needed to be able to anticipate undesirable effects of sludges and effluents containing toxic elements. These undesirable effects could include a) crop yield reductions, b) reductions in nutritional quality of foods and feeds and c) decreases in the quality of fiber products.

2. Selection and breeding of plant varieties for tolerance to and exclusion of toxic elements.

New varieties of plants may be needed to productively use waste treated soils. The development of such crops would insure the use of sludge treated areas and prevent such elements from entering the food chain. A good example would be the development of varieties that exclude Cd from edible parts of food crops.

3. Protection of the food chains.

If we substantially increase the use of sludges and wastewater effluents by their application to croplands we must insure the safety to humans from the use of foods resulting from this practice. Of great, but of lesser importance, is the necessity to determine the effects of this practice on plants and animals themselves.

We believe that toxic chemicals possess a greater hazard from the use of sludges than from the use of effluents. Toxic metals and trace elements are absorbed by plants from the soil to a much greater extent than organics and thus should receive a higher priority. But the organics such as steriods and PCB's should not be ignored, especially when we consider that animals ingest sludges or effluents directly when foraging in pastures treated with these materials.

Because FDA has selected Hg, Pb, Cd, As, Se and Zn as the most important toxic elements in the food chain, this group should receive top priority. When a significant increase is obtained in the content of any of these elements in feed crops is found, feeding trails should be conducted to test the content of the element in meat, eggs or mills products.

4. Reversion and fate of toxic trace elements applied to soils in sludges and effluents.

Basic soil chemistry studies are needed to determine the fate and stability of trace elements, including the identification of compounds and their solubilities. Identification of soluble species, incorporation into existing solid phase components and into secondary soil minerals should be determined. This information will lead to general predictions of problems and solutions for sludge use or lands.

5. Materials Balance

A trace element inventory is necessary to predict long-term consequences of their applications to croplands. This inventory should facilitate the solution to future environmental problems as they arise. Because trace elements can be hazardous in minute amounts, leakage from the soil-root zone should be studied. The erosion from surface soils into lakes and streams should also be assessed. The movement and redistribution of elements within profiles should be determined. Thus a complete accounting of trace elements by way of a materials balance is needed.

6. Effects of toxic elements on microbiological transformations in soils and on soil flora and fauna.

Adverse effects are more likely on higher plants than on soil microorganisms. However, a small effort is needed to determine the effects of relatively high concentrations of toxic elements on normal soil microbiological processes involved in C, N, S and other cycles and on soil biology. Accumulations of toxic chemicals in earthworms and soil insects should be determined in relation to the foodchain for birds and other higher animals.

7. Management of the soluble salts in sludges and effluents.

Because of the tremendous amount of research accomplished, and in progress, on the management of salts in irrigated soils, the need for research on the salts in sludges and effluents has relatively low priority. The management of salts on a basin basis is a high priority research need in many irrigated valleys, but the salt from sludges and effluents are likely to be only a small part of the total salt load in such valleys. In humid areas the dilution of salts is usually sufficient that problems do not develop.

Recommendations:

1. From a toxic chemicals point of view effluent, waters should be considered satisfactory if they meet the 1972 irrigation water quality criteria.
2. A national committee assigned to establish guidelines for sludge disposal on land should be a product of this Workshop and the membership for this committee should come from its participants.
3. Point sources of trace elements into sewage systems should be greatly reduced to decrease the loading rate in land use systems.
4. Extensive monitoring of foods, feeds, agricultural products, soils and waters should be part of presently operating land-use projects.

Participants

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WORKSHOP GROUP 9

Options, Problems and Economics—Engineering Systems

Our report is in three parts. First we made some statements of research needs and arranged them by priority. Our priorities were simply high priority, medium priority, and low priority. Second, we made suggestions as to whether the research should be done by public agencies or by private industry. We also identified several items that we feel are more of an informational need rather than real research needs. And finally, we wanted to express a couple of ideas that we did not explore in any depth because we felt they were more reasonably a concern of another group.

Research Needs—High Priority

We have five high priority needs. We are concerned about the water problems of small communities. Small communities are defined as ten thousand people or less. The collection, treatment and land application of combined sewer system effluent should be considered as a system. Miniaturization of municipal systems is not the way to go for these smaller communities. The small communities may need greater financial assistance because they do not have a large population base from which to generate the large amounts of research funds required. On the other hand, a small increase in per capita costs for large cities would not be significant for the individual.

Number two is winter application and storage. Now, this does sound like a regional problem. But let us consider the restrictions we put on ourselves: during several months of the year and in many parts of the United States we do nothing in the way of land application because of frozen or snow-covered ground. Maybe there are good reasons for it and maybe not. But what happens on frozen land when you apply effluents and sludges? And what is the effect on lagoons when they are full of liquid and it freezes? What happens in the way of concentration of dilution of chemical components? What happens inside of a lagoon when it freezes? What is the fate of the material we put on a watershed? Does it really go right down the stream or what happens to it? What is the effect on soil storage in a frozen condition? And then there is the whole host of various engineering modifications that would be needed in order to simply operate in the winter time. These first two research needs we felt were problems for public agencies.

Three, survey existing operations to develop soil, crop, effluent relationships. This has been identified in other reports. There are systems in operation now. Such systems should provide an excellent opportunity for teams from public and private groups to examine those systems over a period of time to identify changes that might occur. This survey and analysis should be done soon before additional large sums of public funds are spent for more new systems.

Number four, we think is a problem for both public and private research groups. This need is system-wide monitoring. It is sufficiently important that very early effort is recommended. A part of the problem is that we need standard methods of analysis. Analysts are known to debate about which method of analysis is the best and which one really gives the information desired. Also, what should be the frequency of sampling? How big should the sample be? What are the statistical techniques to be satisfied in getting these analyses? What are the parameters? There are so many that have already been mentioned. There must be a set of essential characteristics or essential parameters that must be obtained in order to accomplish the stated objective. Then there is another list of needs that are elective—that is, it would be desirable to have them. But we think this is important. Remember, we are still in our high priority list of needs.

Number five is application systems for forested areas. Again this is regional, but there is a lot of forest land that has unique characteristics. Can we develop application equipment that is better for forest land than what we are using for soybeans and corn, for example. This is research that should be done together by public and private groups.

Research Needs—Medium Priority

Our next research need is a high-medium priority. It deals with the development of acceptable methods of applying raw sewage. If this is possible, the need to separate liquids and solids would be eliminated and costs would be reduced. We think an early part of this is to monitor existing systems where they are actually applying raw sewage. The second part is to develop methods of application.

We have one medium priority which we called "landfall operations." We mean this to be other than land application and partial recycling. Our workshop members were generally displeased with this landfill concept which seemed to lead to the destruction or loss of the resources that actually are in material going into a landfill.

The next need is a medium-low priority, probably will be done by public groups. That is the odor problem. One of the reasons that this priority is low may be because no satisfactory research approach has been developed. Wherever I go people talk about odor problems. But everybody uses a very subjective technique—their own nose. Something surely needs doing but we don't know what. We wanted the odor problem identified.

Research Needs—Low Priority

We have three problems that we say are low priority. One of these has to do with resource extraction. We can surely obtain various metals or gases or biological materials from the sludges. There would probably be private research to do this because if there is money to be made from extracting these materials, it seems likely that an industry will do it. The second low priority need is to develop covers for storage. Several beneficial things might happen in covered storage to the microclimate or microenvironment. You can keep out the precipitation, if that is important. There is a possibility of containing the heat that comes from the treatment process occurring in storage. It might even help to contain odor or change the odor or mask it. Private groups will probably do this research also. The third need is modification of the hydraulic characteristics or sludge. We were shown a graph earlier that hydraulic characteristics do not change by increasing the solids content up to a certain point. Is there a way of improving the pumpability of sludge so that higher quantities of solids can be moved? This research would probably be done by private groups.

Informational Needs

A large body of knowledge is available in terms of understanding and managing an underground aquifer. There are a lot of possibilities of using underground aquifers to manage water of various qualities. The knowledge exists with those who are dealing with underground waters. It might be a good opportunity to invite the participation of the geological survey and related water resource people dealing with underground waters. It might be a good opportunity to invite the participation of the geological survey and related resource people dealing with underground aquifers.

The second informational need is to apply existing knowledge on the control of erosion on the shore lines of lagoons. The builders, the Corp of Engineers, the Bureau of Reclamation, the Soil Conservation Service, Highway Departments, all have to worry about these problems. There are ways of doing something about reducing erosion on shore lines.

The third need is to manage aerosol transport from spray irrigation. Here also there is some knowledge which can be applied to the problem.

The fourth informational need is for a clearinghouse of information containing recent publications and current research. Some way is needed, some quick way, of having publications and research available.

Number five is the need for standard terminology. Several groups have reported this need. It might be worthwhile to point out a couple of the things that were discussed about reading the literature. A research man will report the kinds of observations he makes personally. It is his own data, he can verify it, he knows how good it is, how bad it is and what he can do with it. Then there is secondary data. The author can pick it up from the literature and add it on to what he has obtained. We can communicate personally with colleagues and get some more information and he can make some knowledgeable estimates and total up quite a lot of data. Only part of this the author knows himself, personally, as to its accuracy. And finally, of all things extrapolate that entire data bank and develop conclusions. This process may not be all that bad. But each one of us writes differently as to the conclusions we draw from the data available to us.

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WORKSHOP GROUP 10

Political and Institutional Constraints

The report of the workshop group on Political and Institutional Constraints begins with a warning to the land application community: Unless political and institutional constraints on the land application of effluents and sludges are recognized, identified, and resolved, these projects will likely fail, regardless of their technical, scientific and economic feasibility.

Constraints

Political and institutional constraints on the land application of effluents and sludges have rarely received systematic and scientific consideration. We have arbitrarily listed, as examples, twelve constraints which may affect the implementation and operation of land application technology. This is not an all-inclusive listing, and other constraints will no doubt occur to the reader.

These constraints are:

1. Public attitudes unfavorable to land application systems.
2. Local zoning regulations which may preclude or restrict the application of effluents or sludges to the land. Regulations are often vague in relation to permitted practices.
3. Land use policies which may be non-existent, or which may be technically unrealistic.
4. Financing may be accomplished by tax levies, revenue or general obligation bonds, service fees, and grants-in-aid. Each approach has its own constraints.
5. Nuisance laws which may be enforced if land application systems cause annoyance or inconvenience to any person, group, or organization.
6. Health codes which lack uniformity between jurisdictions or may not be evenly applied to land application systems vis-a-vis other practices such as irrigation.
7. Permit requirements of regulatory agencies which may involve multiple reviews and approvals.
8. Monitoring requirements of regulatory agencies may be ill-defined.
9. Fragmented regulatory agency authority results when numerous levels and agencies of government have jurisdiction over land application projects.
10. Lack of national guidelines for land application systems.
11. The belief that the consequences of implementation of a land application system will be the loss of other desired opportunities.
12. Lack of research information in technical, scientific, and socio-political areas for sound decision making on land application technology.

Research Needs

The workshop group on Political and Institutional Constraints has identified three major study areas for which research needs exist. It is believed that studies in these areas will produce data useful in removing constraints which heretofore have limited large scale use of land application techniques.

Case Histories

The first studies recommended are in the area of Case Histories.

Research effort is needed to compile detailed case studies of successful, as well as unsuccessful, land application programs. The case study approach has been developed and employed by university law and business schools and has been found to be a powerful educational tool for examining and understanding the development of human institutions and interrelationships.

It is proposed that the historical development of at least ten land application projects be thoroughly researched by qualified case writers. The case history project staff should be formed on an interdisciplinary basis and, in general, be composed of engineers, physical and biological scientists, and social scientists. The case studies must be written in a factual, detailed and historic format. Interpretations, judgements, and conclusions must be avoided by the case writers who should, however, exercise discretion with regard to events to be included in the case studies.

Upon completion of the case studies, it is recommended that a separate staff be assigned to review and interpret the cases with the goal of identifying common elements and similarities.

Legal Studies

The second major study area is Legal Studies.

Enabling legislation, judicial decisions, administrative codes, regulations, and guidelines, and local ordinances concerned with applying sludges and effluents on land are to be examined to determine:

1. The powers of typical local governmental units and limitations of those powers to adopt and enforce land-use restrictions and regulations;
2. The problems of authority to acquire land and operate a system for the application of sludge and effluent on land;
3. The methods and restrictions on financing a system for applying sludge and effluent on land;
4. The alternative legal and institutional arrangements available for the ownership of land upon which sludge and effluent are applied; and
5. The extent to which odor, noise, and aesthetic degradation caused by the application of sludge and effluent to land may be considered a nuisance.

Furthermore, studies are recommended to develop an improved strategy for sludge and effluent management, including changes in legislation and other types of institutional arrangements.

Attitudes and Behavior

The third major study area is Attitudes and Behavior.

Detailed sociological study is recommended to determine individual, group, and institutional attitudes and other factors that will affect the success or failure of specific land application programs.

Research

Finally, we recommend a priority effort by the EPA-USDA-Universities Subcommittee on Recycling Effluents and Sludges on Land to obtain adequate funds for all of the scientific, technological, and sociological research which has been identified as needed by this Workshop Conference.

Participants

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WORKSHOP DISCUSSION

COMMENT: Tom Hinesly, Office of the Undersecretary of the Army. I wanted to point out to the educational needs committee that their example of Atlanta, Georgia, the Corp does have a study going on there and I would like you to or like to get you to send your recommendations to them right away, but also if you want to use an example where they don't have one going I think it is fair to say that they are not likely to have one in Indianapolis right away.

QUESTION: Robert Dean, EPA. Again, to the educational group, I would like to ask them what you do with that small segment of the population who will not visit the site because they already know what a stinking place it is.

ANSWER: Bob Walker, University of Illinois. I don't know that I have the answer. There are going to ba a few, who probably will never accept it completely. But we have to do all we can in order to get the majority acceptance. And if you can get them involved in some way, I think the secret is to get them involved early. Now, the one project that we are talking about over at Fulton County is not typical. It is the largest that I know of in the world and I think we can handle these much easier if we were taking Champaign-Urbana's sludge or some of the other around here and I don't think we would have that great a problem. We will never get a 100 percent agreement. And with our processes the important thing is to get the majority. Now, also recognize just a few individuals can upset the thing if they get stirred up enough and I think this is what you are driving at. So the best thing that I know to do is do the best job you can with public relations, try to involve them as much as possible and then continue with the project.

QUESTION: Dict Ford, USDA. Just one additional comment in relation to getting public acceptance. I think that Mr. Bauer down at Arcola has got a good thing going. He is taking in that operation sludge from the local community and perhaps that might be one way of winning over some of the opposition if you are helping them solve their sludge problem all at the same time.

ANSWER: Robert Dean, EPA. There is a lot of apprehension about the very high salt content of sludges relative to effluents. This is true. Digester sludge has a very high conductivity and a high concentration of salts. However, the majority of these salts will not survive oxidation in the soil. They consist mostly of ammonium bicarbonate and ammonium salts of organic acids. So, perhaps we need a test of the residual salts in sludge which will give us a better measure of what will actually enter the groundwater when sludge is applied to the land. I think this is an acceptable research need. It is one that I personally will see gets started on.

COMMENT: Jim Menzies, Department of Agriculture. I wanted to make a comment in regard to public acceptance. We are talking about how to psychologically deal with these problems and there are some physical and practical ways and that is to modify the product. We at Beltsville are attempting to do that, to convert the sludge into compost, and this has more ramifications than first meets the eye because we are quite sure that you can take the neighboring counties sludge and make compost and it will be acceptable to people in the next county whereas it won't be acceptable that it remained the other counties sludge. So, the fact that this is called compost now and not sludge I think is of great public relations value and maybe it is worth putting a little extra expense into it just from this point of view. Also, on the public health point we raised the people that feel that pasteurization is required. We know that we get a pasteurization effect from the composting. We know that it is not as complete as we get from a carefully controlled pasteurization heat treatment plant, but I think this is an alternative that is a valid one to sort of bridge the gap between those who say disinfect and those who say try to get along without the cost of disinfection.

COMMENT: Bob Yeck, USDA-ARS. I would like to comment a little further on this public relations question. We discussed this at considerable length in our meeting and one of the aspects that I would like to put before the group is when you are developing a public relations program, remind the people that they are part of the entire ecosystem. This is one of the bases for the recommendation or the comment that this is a natural process and this is something that people are a part of whether they like it or not. They have to recognize that they don't just exist in a small community by themselves. We spoke in our group about the generation of waste or materials, we did a little calculating very crudely of what the organic output of Fulton County was, for instance, and we rather suspect the organic output of Fulton County that they are shipping out is considerably greater than the organic material that they are getting back into their area. And people have to recognize that they are selling a product to the large city, their city is their user and they have to expect something to come back to them and let's try to sell them the idea that it is a resource, but let's remind them that they are part of the system. They are also, they don't just stay in Fulton County, if we want to use that example. They frequently, I am sure several of those people travel to Chicago and use the facilities in Chicago and some of their own material is being returned to them. Now, I don't know how you put this in the record but these types of things are to remind the people that they are not just living in one little area. They are part of a bigger system and this is one of the major points I think you must get across in public relations systems.

QUESTION: B. L. Seabrook, EPA. Again, on the subject of public relations. We had a film here, Wealth from Waste, where they called sludge HYDIG and they did this in England because they did have a public relations problem and they came up with a fancy name, Highly Digested Sludge, shortened to HYDIG. And they found that people that objected to sewerage and objected to sludge, didn't seem to object to HYDIG. So, maybe a rose by any other name is not as sweet. Anyway, it seems to me that semantics is an important part of our business. Disposal is one of those words. When you talk about disposal of sewerage wastes, a lot of people bristle, but when you talk about land application and land utilization and recycling and reuse, people seem to relax, and I would suggest that we, as far as possible, avoid the word disposal unless we actually mean disposal. And I would suggest that when people talk about land disposal, they stop using the word disposal and we talk about application and land utilization and land reuse or what ever term you want to call it, but unless you mean digging a hole in the ground and dumping it in, which is disposal, unless you mean disposal, let's stop using the word disposal.

QUESTION: Ray Harris, USDA, Forest Service. We spent five days here of valuable time. I think we will all agree to that and this is so that the agencies can start to work together on these problems. We have addressed many important ones as high priorities. For example, monitoring has to be done on a national level. Work must be done to co-ordinate and to maintain the integrity of the data and researchers that are doing it. Would you tell us, Darwin, how you are going to take all of this information and put it together and put together some kind of coordinating or informational committee so that we can start seeing some real results of inter-disciplinary action and interaction and working together on calling problems together, something which we have never done so far, although this is just one of probably a hundred types of symposiums that has been held?

ANSWER: Darwin Wright, EPA. When this committee was created over a year ago, it was created with the principal directive of developing mechanisms for coordinating the research between EPA, USDA and land grant universities. The first step the sub-committee made was to find all the players in the game and define what we knew and what we should know. Hopefully this will come out as a result of this meeting this week. I might add that each member of this group, all of you who have registered, will receive a copy of the proceedings.

Getting back to your question. Now, here we are and what or where do we go from here? I think I raised this issue on Monday and now that you have all had a week to think about it, we don't really have time to discuss it in detail, so I would like to ask you to collect your thoughts and drop me a line.

Right now what I see happening is that the sub-committee will get together and try to develop mechanisms for coordinating the research. I have heard several things suggested and I have in the back of my mind that I think we could develop the national strategy for land application of municipal effluents and sludges. One of the ways of getting coordination on a program like this is to take a number of demonstration sites and develop a program around each site. Have them graphically or geographically and climatically oriented and use existing sites wherever possible. I think Fulton County might prove to be a perfect place to work, depending upon the type of research, development or demonstration needed. We do need the research as soon as possible. I think we have to consider in detail the suggestion by Mr. Myers of examining case histories of existing sites. But it is difficult for me to say exactly where the committee is going.

QUESTION: Tom Hinesly. Darwin, I would like to ask one question. I would like to know what effect this will have on the availability of research funds because there are some of us sitting in this audience, you know, that have ongoing research and others have had proposals in which we have answered some of these questions that we have come up here with and they have been recently turned down. Our support has been discontinued. It was aimed at answering some of these questions and I am rather confused. Here we come back from meeting to meeting and we outline the research needs and then sometimes we get some of these started and then they are not continued. So, I just wondered if you might comment on that.

ANSWER: Darwin Wright, EPA. I guess my comment, Tom, and that is a little bit of a loaded question because you are about in the same position as I am, maybe we have the 118 registered here that become vocal spokesmen to take the message back to the people you know. I have a limited amount of funds within the Municipal Pollution Control Division of EPA, but I can't put all my eggs in one basket because as everyone knows this is not a panacea and we have other problems that have to be solved also.

QUESTION: Tom Hinesly. We are talking mainly about an agricultural crop here and most state legislatures have not recognized that the colleges of agriculture are involved in solving municipal problems in this area. Those of us in universities who want to do research of this nature in colleges of agriculture have to depend on federal funds, at least at this point, because I don't think we can count on our state legislature as appropriating funds for us to solve this problem, simply because they don't know that we are involved.

ANSWER: Darwin Wright, EPA. Yes, Tom but why don't they know you are involved? Are we afraid to tell them?

QUESTION: Tom Hinesly. That is a problem sometimes. It is true, because the down state people don't want this type of research supported. And the people who live in cities, I don't know how we get the information to them, that they need it.

ANSWER: Darwin Wright, EPA. Well, let me just go on record here. The sub-committee will tackle this problem, how we get the word across to both local people for local support and to our own State and Federal people to support research in land application of municipal effluents and sludges.

COMMENT: Dick Ford, USDA Extension Service. From an educational and informational standpoint, I just wanted to support two recommendations that were made. One, is this need for case studies. You who have ever used case studies know they are a very effective tool and secondly, this recommendation of needing to collect from the different universities or institutions of what has been done in certain research fields. We talked about this quite a bit in our group and didn't really know how to get a hold of it. That is a good question: how do you get a hold of information from all the universities of what is going on or has been done.

CHAIRMAN: Any other comments?

COMMENT: George Ward, Consulting Engineer. I have gone to a lot of these conferences and I am sure others have, but there is a rare blend of people here that I think is unique and I want to leave with one recommendation, that if you can and if it is practical and if everyone here is willing, I would like to urge that you somehow try to reschedule a similar type meeting, hopefully starting with about the same group and maybe blend it with others that you might find. I don't know if you can do this or not, but most conferences we go to, we get a lot of information, get all excited and go home and forget about it. That may happen again, although I got four tons of notes and I will read them all, but I think it might be helpful to try a similar meeting with a similar bunch and on behalf of Oregon and our great country, I would like to have you out our way if you would.

QUESTION: Darwin Wright. That sounds like a pretty good idea. I am going to put Rufus Chaney on the spot. Rufus, what do you think about having another research needs workshop a year from now?

ANSWER: Rufus Chaney, USDA. When I was talking with Darwin, I had Tom Hinesly's comments. If we don't fund now what good is it to have ten more conferences. We have a pretty good list of research needs and I think that perhaps the most important thing of all is somehow to get this work started. I don't know whether you have to personally send copies of this report to every member of Congress and every member of the White House to get it started, but no more meetings are worthwhile until some more work is on the way. That is the problem of workshops—to list needs. We have a good list and a big need for money right now.

COMMENT: Paul Blakeslee, State of Michigan. I think I would like to just toss in a word of caution about what I know is going to happen. We are talking here about a vast number of research needs and I think I support virtually everything that has been said as to the unknowns. I also know that as I go back there are going to be plans laying on the desk for projects, for systems, for things that are mandated by time schedules, construction time schedules in legislation, in state enforcement activities and so on. At this point in time it is a blend of all the technologists and as long as there are serious questions on land disposal technology, the approach is going to have to be one of proceeding with caution and looking for all the unknowns that we can. We are going to have to do the same thing with some of our past historical approaches too, but Michigan is probably one of the few states that is represented here. We are going to go back and we are going to look and we are going to try to make the best judgments we can, but until the results of this thing are boiled together, we can't make all the necessary decisions.

COMMENT: Parker Pratt, University of California. I would like to comment a little more optimistically than Rufus does, although I agree with him, the chance to communicate and challenge other people and be challenged with an interdisciplinary mix of people is really worthwhile to all of us. I have had a number of experiences recently of this kind and I am tremendously impressed with the ability of interdisciplinary mixes in a group to really come up with some solutions to problems using data that we already have. And I have learned a lot in this conference about problems that I didn't really know existed and I am sure that you have and so I would say let's get together a year from now or two years from now with the same group and compare notes again. Even if we feel like our list of research priorities has not had a tremendous effect on getting more money. There is work going on, everyone here is doing some kind of a research project on the sludge or effluents, maybe that is not true with all of us but we know of work going on and getting together actually to compare notes is a worthwhile objective in and of itself.

COMMENT: Robert Dean, EPA. I am speaking for a committee on the Dimensions of the Problem. We did recommend that a meeting such as this be held and we carefully added the point to review new data. Now, this does not mean data recently developed necessarily, but data that hasn't previously been brought to our attention and I would like to make a plea that we spend a little more time looking at the foreign data. I have found a great deal of very valuable information in the Swedish literature. I will have the more important parts of the Swedish literature translated. There is a great deal to be found in the German literature. Not many of us read enough of what is available in England. We have heard about experiences in other countries, but too many people have looked at this as if it was solely a USA problem and if we haven't worked on it in this country, we can't believe what we hear. I suggest, therefore, that in the next meeting we do have some responsible foreign delegates.

QUESTION: Harry Geyer, Extension Service, USDA. I was interested in your comment, Darwin, of bringing other agencies into the operation and from the public health aspects. The thought occurred to me that here is an area where in the Department of Interior, the Bureau of Fish and Wild Life, we may have the opportunity through research which they could be conducting to assist us in making extrapolations of the implications of these species having both the carnivores and the herbivores that would be utilizing some of the crops grown thereon or the plants which would give us an insight into some of the implications and concerns that we currently have.

ANSWER: Darwin Wright, EPA. Yes, I think it is important that we pull together the other agencies. actually the sub-committee had started on this, Tom Hinesly from the Undersecretary of the Army's Office, and CEQ have sat in on some of our workshop committees, and John Frey from OWRR is interested in following on with us. I think the decision that has to be made is a higher level decision. We should develop a coordinating committee and we sort of have been leaning towards CEQ to do this.

All I really want to say in closing is that this morning I thought maybe I could take some notes and try and summarize what the ten workshop chairman had said and as I listened, I guess I was more impressed as to what they were saying and failed to put together any summary which probably would have taken 10 or 15 minutes anyway, so just in closing as far as the workshops are concerned, I think you have all done an outstanding job.

Th other thing I think we should have special recognition for, again, the arrangements committee, Sig Melsted, Jim Evans and John Trax. So, in closing I just want to thank each and everyone of you for coming and I hope we can keep this dialogue going.

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